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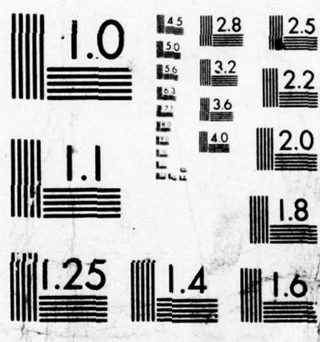

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A mathematical model capable of computing flight path and orientation data for helicopters having a single main rotor and a vertical tail rotor is presented. The model calculates power level and control angles in steady (trimmed) flight for ascending, level, or descending flight paths. Provisions are included for simulating a fixed wing, auxiliary thrust, and a movable horizontal tail whose incidence angle is linked to the main rotor longitudinal cyclic control. The model is coded in Fortran Extended to run on the CDC 6700 computer system. Output from this model is used in the generation of aiming data for the delivery of unguided ordnance.

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FOREWORD

The computer model described herein was developed to provide accurate space-orientation data for helicopters in "trimmed" (unaccelerating) flight. The data generated with this model will be used in generating aiming data for helicopter delivery of unguided weapons. Formulations and methodology were provided by Dr. Barnes W. McCormick, Head, Department of Aerospace Engineering, Pennsylvania State University under contract to the Naval Surface Weapons Center (NAVSWC), Dahlgren, Virginia. The work was performed in the Air-Launched Weapons Branch, Exterior Ballistics Division, Strategic Systems Department, under Naval Air Systems Command Airtask Number A532-5323/009-2/7-0000000-20, Work Request Number N0001977WR78712.

This report was reviewed and approved by J. E. Cuevas, Acting Head, Air-Launched Weapons Branch; and H. P. Caster, Head, Exterior Ballistics Division.

Released by:

R. A. NIEMANN, Head
Strategic Systems Department

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INTRODUCTION

BACKGROUND

The Naval Surface Weapons Center (NAVSWC), Dahlgren, Virginia, has the responsibility for providing aiming data to support Fleet use of air-launched weapons from all Navy aircraft. In the case involving rotary-wing aircraft, aiming data for desired release conditions were not always readily computable due to lack of sufficient angle-of-attack data. Because of the wide variety of applications for the helicopter and its maneuverability, an accurate yet inexpensive method of generating angle-of-attack and position/orientation data for any desired delivery technique was needed. For this reason, efforts concentrated on obtaining a computer model which will provide angle-of-attack and position/orientation data.

There are currently no computer models available which are cost effective to operate and provide the desired accuracy. Consequently, a two-part effort was initiated. The first involves a model to calculate angle-of-attack data for use in generating aiming data for helicopters in a trim state. The second effort involves a dynamic model which will generate time-position/orientation data for non-trimmed releases and safe separation analysis. The second model may incorporate the results of the first model. This report documents the model which has resulted from the initial effort.

OBJECTIVE

The objective of this effort has been to develop a means of determining time-position/orientation data for use in computing sight-setting information for helicopter weapon delivery. Any method for obtaining such data must provide the required data quickly and accurately at a reasonable cost. The desired accuracy chosen at the beginning of this effort was to obtain angle of attack within plus or minus one half degree. For operating time, the objective was to obtain the needed accuracy in as short a running time as possible. The method chosen to obtain these objectives was to ignore any variables not of immediate concern in determination of angle of attack (e.g., stress analysis, blade flexibility, etc.).

RATIONALE

GENERAL

The Basic Helicopter Performance and Control Model is a Fortran Extended program which computes the power and control angles for a helicopter in steady flight. This section provides description of the theory and techniques involved. If more detailed information is required, the reader is referred to Reference 1. Appendixes A through C provide all information necessary for an individual familiar with Fortran to set up and run the Basic Helicopter Performance and Control model. Appendix D provides a brief comparison with actual AH-1J helicopter flight test data. Appendix E provides a list of symbols and definitions.

The method employed in generating trim parameters is a moment-balancing iteration technique. Flight parameters are input, an angle-of-attack estimate is made and the resulting control angles, forces, and moments about the aircraft center of gravity are then computed by means of closed-form approximations. Based on the resulting moment unbalance, a new angle of attack is computed using the Pegasus algorithm (Reference 2) and the computations are repeated. This procedure is continued until the moment unbalance is very small (arbitrarily chosen to be $\leq$ helicopter gross weight/500) at which point the helicopter is considered "trimmed," power required is calculated, and resulting data are printed.

HELICOPTER TRIM

A helicopter is "trimmed" when the sum of all of the moments about the center of gravity (cg) is zero, and all forces are in balance. The moments considered include contributions from the rotor, fuselage, and horizontal tail. For all forces to be in balance, the vertical components of rotor thrust, wing lift, horizontal tail lift, and fuselage lift must equal the weight (W) of the helicopter. In addition, the sum of the rotor thrust component in the direction of flight and any additional propulsive force must be equal to the sum of the fuselage drag, wing drag, horizontal tail drag, and rotor drag.

Figure 1 shows these forces, moments, and relative velocities. The rotor is positioned some distance (Y) behind and (H) above the cg. The horizontal tail is a distance (ℓ_t) behind the cg and is positioned at an incidence angle of i_t. The i_t may be linked in some manner to the main rotor longitudinal cyclic pitch.

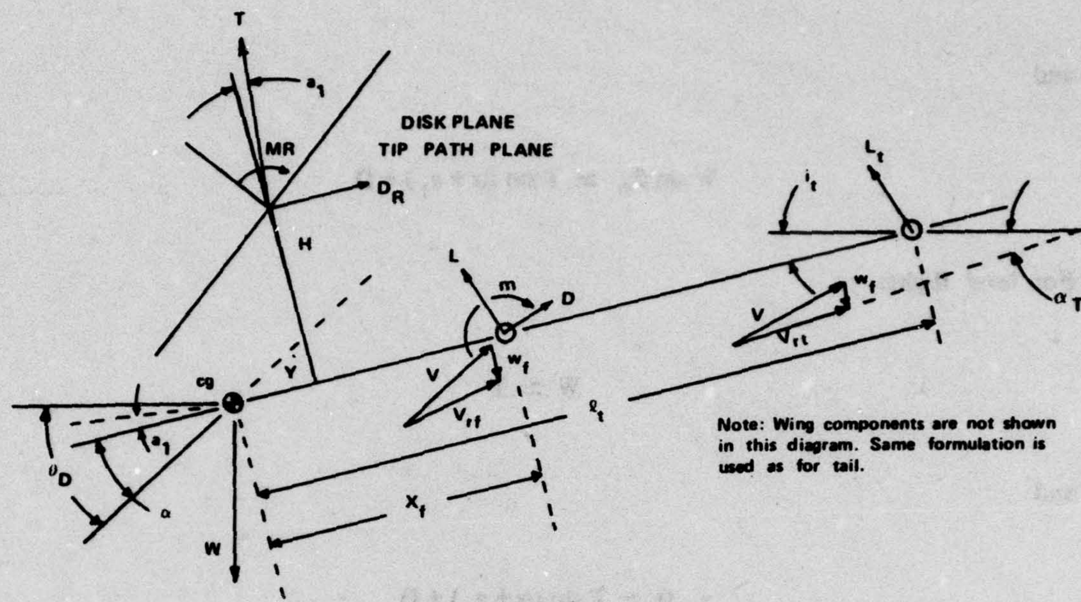

Figure 1. Helicopter Forces, Moments, and Relative Velocities

The angle of attack of the tail is reduced by the downwash from both the rotor and the wing (not shown) ahead of it. The resulting angle of attack is given as α_t. Fuselage lift (L), drag (D), and moment (m) are assumed to be acting at a distance (X_f) aft of the cg as shown in Figure 1.

The resultant forces are shown in Figure 2. To account for descent, L is neglected and α and a_1 are assumed small so that

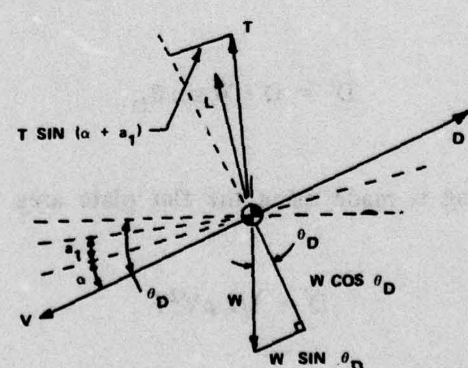

Figure 2. Forces on a Helicopter in Steady Descent

$$W \cos \theta_D \simeq T$$

and

$$W \sin \theta_D \simeq T \sin(\alpha + a_1) + D$$

For level flight:

$$W \simeq T$$

and

$$0 \simeq T \sin(\alpha + a_1) + D$$

Therefore, in order to determine trim angles and power required in descent, the level flight case is evaluated with an "equivalent" weight, W′, and an "equivalent" drag, D′, given by

$$W' = W \cos \theta_D$$

and

$$D' = D - W \sin \theta_D$$

The correction to the drag is made using the flat plate area (f). Since

$$D = 1/2\, \rho V^2 f$$

$$f = \frac{D}{1/2\,\rho V^2}$$

which implies

$$f' = \frac{D - W \sin\theta_D}{1/2\,\rho V^2} = f - \frac{W \sin\theta_D}{1/2\,\rho V^2}$$

SIMPLIFIED THEORY OF TRANSLATIONAL FLIGHT

Rotor aerodynamics and dynamics parallel the treatment given in Reference 1. Cursory treatment is given below.

Downwash velocity (w) for a lifting rotor in forward flight can be defined by

$$w = \frac{C_T}{\pi AR} \cdot V'$$

which implies

$$C_T = \frac{w\pi AR}{V'}$$

Since the aspect ratio $AR = b^2/S$ where $b = 2R$ (R = rotor radius), we have

$$C_T = \frac{w\pi 4R^2}{SV'}$$

and

$$T = C_T qS = \frac{w\pi 4R^2}{SV'} \cdot \frac{\rho (V')^2}{2} \cdot S = \rho V' \pi R^2 2w \tag{1}$$

where ρ = air density and V' is the vector sum of induced (downwash) and translational velocities.

Induced power (P_i) now becomes

$$P_i = Tw = T\left(\frac{T}{\rho V' \pi R^2 2}\right) = \frac{T^2}{2\rho V' \pi R^2}$$

To account for the increase in induced power above the ideal, the term EI is introduced. The resultant equation is

$$P_i = (1 + EI)Tw = (1 + EI)\frac{T^2}{2\rho V \pi R^2}$$

where EI is typically between 0.12 and 0.15.

If the thrust vector is tilted forward through some small angle (α), useful work is being performed at the rate ($T\alpha V$). Thus, in general, the ideal power (P) required by a rotor in forward flight is

$$P = T\alpha V + P_i = T(\alpha V + w)$$

For steady forward flight, the horizontal component of thrust ($T\alpha$) must equal the parasite drag of the helicopter. Therefore, $T\alpha V$, termed the parasite power, is defined by

$$P_{PAR} = DV$$

In addition to the ideal power, the rotor requires power to overcome the profile drag of the rotor blade sections. This power is referred to as the profile power (P_P). Total power required by a helicopter rotor in forward flight is therefore composed of three parts

$$P = P_i + P_{PAR} + P_P \qquad (2)$$

From Equation (1), substituting for V we obtain

$$T = \rho(V^2 + w^2)^{1/2}\pi R^2 2w = 2\rho\pi R^2(V^2 w^2 + w^4)^{1/2}$$

which implies

$$(V^2 w^2 + w^4)^{1/2} = \frac{T}{2\rho\pi R^2} = \frac{T}{2\rho A}$$

or

$$V^2 w^2 + w^4 = 1/4\left(\frac{T}{\rho A}\right)^2$$

and, using the quadratic formula, we obtain

$$w^2 = \frac{-V^2 \pm \sqrt{V^4 + \left(\frac{T}{\rho A}\right)^2}}{2}$$

or

$$w = \left[1/2\left(-V^2 + \sqrt{V^4 + \left(\frac{T}{\rho A}\right)^2}\right)\right]^{1/2}$$

For a constant value of C (chord length), C_ℓ, and an assumed constant value of C_d, P_P can be defined as

$$P_P = P_{P_0}(1 + \mu^2)$$

where

$$P_{P_0} = \text{profile power required in hover } (\mu = 0)$$
$$= C_{P_p}\rho A V_T 3$$

where

C_{P_p} = profile power coefficient

$= \frac{\sigma \overline{C_d}}{8}$ for a constant C_ℓ

In addition to overcoming the torque produced by the profile drag of the blades, more power is required because of the blade profile drag

$$\Delta P_{PAR} = 2\mu^2 P_{P_0}$$

Because of similarity of form, we include this in profile power to get

$$P_P = P_{P_0}(1 + 3\mu^2)$$

The coefficient of μ^2 varies from manufacturer to manufacturer. Because of aerodynamic uncleanliness of the root end of the rotor blades, this constant is usually increased in practice to at least 4.

ROTOR DYNAMICS

Two dimensionless ratios are ascribed to a given state of rotor operations: tip speed ratio (μ), and inflow ratio (λ). The ratio of rotor translational velocity to the velocity of the tip due to rotation is μ.

$$\mu = \frac{V}{\Omega R} = \frac{V}{V_T}$$

Inflow rate, λ is the ratio of the net velocity up through the disk plane to the tip speed. Calculation of λ requires definition of α, the angle of attack of the disk plane. The angle between the incoming free-stream velocity and the rotor disk plane is α. If the disk plane is nose up, α is positive.

If w is the downwash velocity at the rotor and if α is assumed small, then

$$\lambda = \frac{V\alpha - w}{V_T}$$

Collective pitch (θ_0), total twist (θ_T), lateral cyclic pitch (θ_1), longitudinal cyclic pitch (θ_2), coning angle (β_0), longitudinal flapping (a_1), lateral flapping (b_1), disk plane angle-of-attack (α), tip speed ratio (μ), inflow ratio (λ), and thrust coefficient (C_T) are all interrelated. An explanation of these relationships is given in Reference 3, and pertinent facts are summarized below.

The results for a uniformly twisted non-tapered blade yield

$$C_T = \frac{a\sigma}{2}[\lambda T_1 + (\theta_0 + K_\beta \beta_0)T_2 + \theta_T T_3 + (\theta_2 - K_\beta b_1)T_4]$$

If we assume lateral flapping $(b_1) = 0$ and solve for θ_0, we obtain

$$\theta_0 = \left[\frac{2C_T}{a\sigma} - \lambda T_1 - K_\beta \beta_0 T_2 - \theta_T T_3 - \theta_2 T_4\right]/T_2$$

where T_1, T_2, T_3, and T_4 are functions of μ and B_0 is the effective dimensionless main rotor radius.

$$T_1 = \frac{1}{2}\left(B_0^2 + \frac{1}{2}\mu^2\right) \qquad T_3 = \frac{1}{4}B_0^2(B_0^2 + \mu^2)$$

$$T_2 = \frac{1}{3}\left(B_0^3 + \frac{1}{2}\mu^2 B_0\right) \qquad T_4 = \frac{1}{2}\mu\left(B_0^2 + \frac{1}{4}\mu^2\right)$$

where

a = section lift curve slope
σ = rotor solidity

C_T is obtained from an average thrust giving the same impulse/revolution as the time-varying thrust.

The coning angle (β_0) can be obtained from

$$\beta_0 = \gamma_F [\lambda F_1 + (\theta_0 + K_\beta \beta_0) F_2 + \theta_T F_3 + (\theta_2 - K_\beta b_1) F_4] - \tau$$

or, assuming lateral flapping (b_1) = 0,

$$\beta_0 = \gamma_F [\lambda F_1 + \theta_0 F_2 + K_\beta \beta_0 F_2 + \theta_T F_3 + \theta_2 F_4] - \tau$$

where

$$F_1 = \frac{1}{3} B_0^3 \qquad F_3 = B_0^3 \left(\frac{1}{5} B_0^2 + \frac{1}{6} \mu^2 \right)$$

$$F_2 = \frac{1}{4} B_0^2 (B_0^2 + \mu^2) \qquad F_4 = \frac{1}{3} \mu B_0^3$$

$$\tau = \frac{M_W}{I_F \Omega^2} \qquad \gamma_F \;\mu\; \frac{C \rho a R^4}{2 I_F}$$

I_F is the blade moment of inertia about the flapping axis, and M_W is the blade weight moment about the flapping axis.

Longitudinal flapping (a_1) is given by

$$a_1 = \lambda A11 + (\theta_0 + K_\beta \beta_0) A12 + \theta_T A13 + (\theta_2 - K_\beta b_1) A14$$

where

$$A11 = \frac{4(\mu B_0^2/2 - \mu^3/8)}{B_0^2 \left(B_0^2 - \frac{1}{2} \mu^2 \right)} \qquad A13 = \frac{2 \mu B_0^2}{B_0^2 - \frac{1}{2} \mu^2}$$

$$A12 = \frac{8 \mu B_0}{3 \left(B_0^2 - \frac{1}{2} \mu^2 \right)} \qquad A14 = \frac{B_0^2 + \frac{3}{2} \mu^2}{B_0^2 - \frac{1}{2} \mu^2}$$

Letting lateral flapping (b_1) = 0, and solving for θ_2, one obtains

$$\theta_2 = (a_1 - \lambda A11 - (\theta_0 + K_\beta \beta_0)A12 - \theta_T A13)/A14$$

Lateral flapping (b_1) is defined by

$$b_1 = \beta_0 B11 - (\theta_1 - K_\beta a_1)$$

where

$$B11 = \frac{4\mu B_0}{3\left(B_0^2 + \frac{1}{2}\mu^2\right)}$$

Letting $b_1 = 0$ and solving for θ_1, we obtain

$$\theta_1 = \beta_0 B11 + K_\beta a_1$$

CORRECTION FOR BLADE STALL

Reference 4 gives a correction to the power coefficient given in Equation (2). This correction (C_{P_s}) accounts for the increase in rotor torque due to retreating blade stall. C_{P_s} is based on the following assumptions: (1) a jump of 0.08 occurs in the section drag coefficient at stall, and (2) the disk area within which blade stall exists is a pie-shaped segment of minimum dimensionless radius (X_s) that is symmetric about $\psi = 270°$ (Figure 3). With these assumptions, C_{P_s} can be defined as

$$C_{P_s} = \frac{\sigma}{24\pi}(1-\mu)^2(1-X_s)\sqrt{1-X_s^2}\,. \tag{3}$$

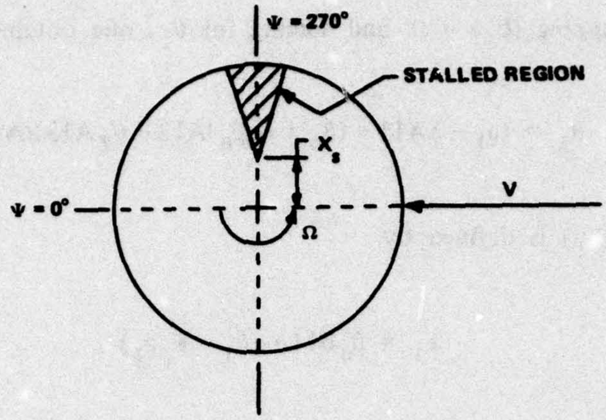

Figure 3. Blade Stall Pattern

The dimensionless radius (X_s), outboard of which blade stall is present, can be found by equating the section angle of attack of a general rotor section at $\psi = 270°$ to α_{max}, the angle of attack corresponding to $C_{\ell_{max}}$.

If θ is the pitch angle of a rotor section relative to the disk plane, the angle of attack of the section is given by

$$\alpha(r,\psi) = \theta - \frac{V\beta \cos\psi + w + r\dot{\beta} - V\alpha}{\Omega r + V \sin\psi}$$

where r is the radius to the section. Dividing top and bottom by $\Omega R = V_T$, we obtain

$$\alpha(r,\psi) = \theta - \frac{\mu\beta \cos\psi + \frac{w}{V_T} + \frac{r}{R}\frac{\dot{\beta}}{\Omega} - \mu\alpha}{\frac{r}{R} + \mu \sin\psi}$$

or, since $r/R = X$ and $\lambda = \mu\alpha - w/V_T$

$$\alpha(r,\psi) = \theta - \frac{\mu\beta \cos\psi + X(\dot{\beta}/\Omega) - \lambda}{X + \mu \sin\psi} \tag{4}$$

If one substitutes for β and θ using

$$\theta = \theta_0 + \theta_T X + \theta_1 \cos\psi + \theta_2 \sin\psi + K_\beta \beta$$

and

$$\beta \cong \beta_0 - a_1 \cos\psi - b_1 \sin\psi$$

and also using the fact that

$$\frac{\dot{\beta}}{\Omega} = \frac{d\beta}{d\psi} = a_1 \sin\psi - b_1 \cos\psi$$

one obtains, from Equation (4)

$$\alpha(r,\psi) \cong \theta_0 + \theta_T X + \theta_1 \cos\psi + \theta_2 \sin\psi + K_\beta(\beta_0 - a_1 \cos\psi - b_1 \sin\psi)$$
$$- \frac{\mu(\beta_0 - a_1 \cos\psi - b_1 \sin\psi)\cos\psi + X(a_1 \sin\psi - b_1 \cos\psi) - \lambda}{X + \mu \sin\psi}$$

Assuming b_1, lateral cyclic, is equal to zero, one obtains

$$\alpha(r,\psi) = \theta_0 + \theta_T X + \theta_1 \cos\psi + \theta_2 \sin\psi + K_\beta(\beta_0 - a_1 \cos\psi)$$
$$- \frac{\mu\beta_0 \cos\psi - a_1 \cos^2\psi + X a_1 \sin\psi - \lambda}{X + \mu \sin\psi} \tag{5}$$

Setting Equation (5) at $\psi = 270°$ to α_{max} results in

$$\alpha_{max} = \theta_0 + \theta_T X_s - \theta_2 + K_\beta \beta_0 + \frac{1}{X_s - \mu}(\lambda + X_s a_1) \tag{6}$$

or, equivalently

$$\alpha_{max}(X_s - \mu) = \theta_0(X_s - \mu) + \theta_T X_s^2 - \theta_T X_s \mu - \theta_2(X_s - \mu) + K_\beta \beta_0 (X_s - \mu) + \lambda + X_s a_1$$

or

$$\theta_T X_s^2 + (-\alpha_{max} + \theta_0 - \mu\theta_T - \theta_2 + K_\beta\beta_0 + a_1)X_s + (\alpha_{max} - \theta_0 + \theta_2 - K_\beta\beta_0)\mu + \lambda = 0$$

or, letting

$$\Gamma = \alpha_{max} - \theta_0 + \theta_2 - K_\beta\beta_0$$

$$C_s = \mu\Gamma + \lambda$$

$$B_s = a_1 - \mu\theta_T - \Gamma$$

one gets

$$X_s = \frac{-B_s + \sqrt{B_s^2 - 4\theta_T C}}{2\theta_T} \tag{7}$$

The correction given in Equation (3) must, however, be modified. The derivation given in Reference 4 assumes a pie-shaped stall region in the blade disk (see Figure 3). Depending on the inflow ratio and blade twist, however, it is possible for the blade section angles of attack to be higher inboard than at the tip, resulting in the stall pattern shown in Figure 4.

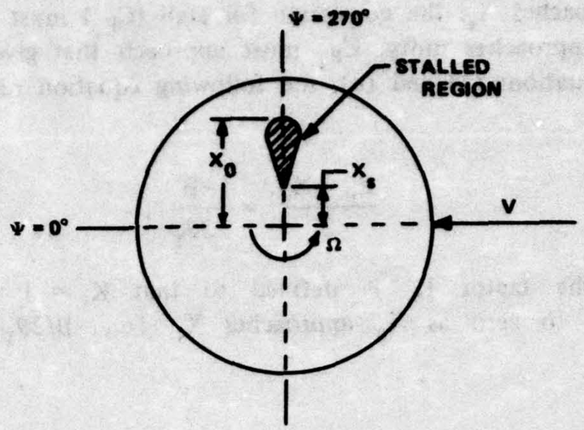

Figure 4. Blade Stall Pattern

For a given value of X_s, the stall pattern of Figure 4 will require less power than that assumed by Equation (3). The dimensionless radius X_0 is the other root of Equation (6) and is given by

$$X_0 = \frac{-B_s - \sqrt{B_s^2 - 4\theta_T C}}{2\theta_T} \tag{8}$$

To correct Equation (3) for this possible "inboard" stalling, one assumes that the stalled region is diamond-shaped. This assumption is shown in Figure 5 for varying values of μ.

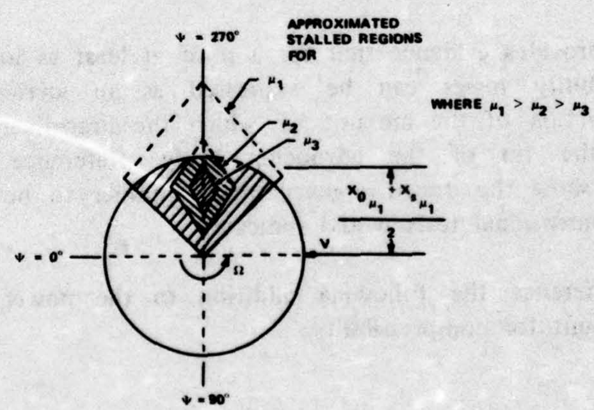

Figure 5. Approximated Stall Regions

As X_0 approaches X_s, the correction for stall (C_{P_s}) must vanish. As the average of X_0 and X_s approaches unity, C_{P_s} must approach that given by Equation (3). If one combines Equations (7) and (8), the following equation results

$$\frac{X_0 + X_s}{2} = \frac{-B}{2\theta_T} .$$

Therefore, the factor K_s is defined so that $K_s = 1$ for $-B/2\theta_T \geqslant 1$ and decreases linearly to zero as X_0 approaches X_s (i.e., $-B/2\theta_T \rightarrow X_s$). The resulting equation is

$$C_{P_{s\,CORRECTED}} = K_s C_{P_s}$$

where

$$K_s = \begin{cases} -\left(\dfrac{\dfrac{B_s}{2\theta_T} + X_s}{1 - X_s}\right) & \text{for} \quad -\dfrac{B}{2\theta_T} < 1 \\ 1 & \text{for} \quad -\dfrac{B}{2\theta_T} \geqslant 1 \end{cases}$$

CORRECTION FOR COMPRESSIBILITY EFFECTS

Reference 5 provides evidence that for a μ of at least as low as 0.2 to as high as 0.5, compressibility losses can be expressed as an increment in C_P/σ. This increment is a function of the amount by which the drag-divergence Mach number is exceeded at the tip of the advancing blade. Reference 5 also states that experimental data show the drag-divergence Mach number to be approximately 0.06 higher than two dimensional tests would indicate.

From this reference the following addition to the power coefficient can be formulated to account for compressibility:

$$C_{P_c} = \sigma[0.012\Delta Md + 0.100(\Delta Md)^3]$$

where

$$\Delta Md = M_T(1+\mu) - M_{CRIT} - 0.06$$

or, since M_T is the tip Mach number

$$\Delta Md = \frac{V_T}{V_c}(1+\mu) - M_{CRIT} - 0.06 = \frac{V_T + V}{V_c} - M_{CRIT} - 0.06$$

where

M_{CRIT} is the critical Mach number of the advancing blade at $\psi = 90°$. Using Equation (5) and setting $\psi = 90°$, X = 1, and $b_1 = 0$ one obtains

$$\alpha_{90} = \theta_0 + \theta_T + \theta_2 + K_\beta \beta_0 + \frac{\lambda - a_1}{1+\mu} \tag{9}$$

The following expressions are used to estimate M_{CRIT}

$$M_{CRIT} = M_{CRIT_0} - m_1 C_\ell$$

where M_{CRIT_0}, the critical Mach number for $C_\ell = 0$, can be obtained for various airfoils from Reference 6. For the advancing blade at $\psi = 90°$, one obtains

$$C_\ell = A_0 * \alpha_{90}$$

where A_0 is the slope of the section lift curve.

Thus,

$$M_{CRIT} = M_{CRIT_0} - m_1 * A_0 * \alpha_{90}$$

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APPENDIX A

PROGRAM LISTING

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C  BASIC HELICOPTER PERFORMANCE AND CONTROL--MCCORMICK
C
      REAL MCR0,M1,MU,IFA,LAMDA,KP,KS,M,KBETA,LT,MUT,MCRIT,N,LV,MOMENT
      REAL MUF(10),MW,LAM(10),MOMNT1,MOMNT2,MFUSE,MTAIL,MWING
      DIMENSION OVNOT(10),OHPI(10),OHPP(10),OHPPAR(10),OHPS(10),OHPC(10)
      DIMENSION OCLBT(10),OCLBAR(10),CASE(20),CCOUNT(10),OHPT(10),
     1OHP(10),OHPTC(10),OA1(10),OALPHA(10),OBETA0(10),OTHETO(10),
     2OTHET1(10),OTHET2(10),OPHI(10)
      DIMENSION OTPRES(10),OMOMNT(10),OALPHT(10),OTPCTQ(10),OVIND(10)
C
C  INPUT
C
      READ(5,101)CASE
C  AIRFOIL DATA
      READ(5,100)DEL0,DEL1,DEL2,CLMAX,A0INCD,A4,A10,MCR0,M1
C  FUSELAGE AND GENERAL DATA
      READ(5,100)F,FV,RTRSTA,CGSTA,H,GW,CM0,CMALPD,EI,KF,AFD,CL0,XF,
     1N,HT,SHPMAX,TRQPRS,DNWSHK,HPACC,RTRDWK,TE,HE,FUSEMK,THET2P,THET2N
C  TAIL TRIM SURFACE DATA
      READ(5,100)ST,ALPH0D,ALPH1D,ALPH2D,ART,TLSTA,CLTMXP,CLTMXN
C  VERTICAL TAIL SURFACE DATA
      READ (5,100)STV,ALPHV0,ARV,VTSTA,HV
C  MAIN ROTOR DATA
      READ(5,100)VT,DMR,B,C,W,WT,E,DEL3D,THETTO
C  TAIL ROTOR DATA
      READ(5,100)VTT,DT,BT,CTR,TRSTA
C  OPERATING CONDITIONS
      READ(5,100)DELVKT,VFIN,ALT,RHO,TEMP,PRESS,VC,THDESD,HRTR
C
C  IF RHO NOT EQUAL 0.  INPUT DENSITY AND VC ARE USED
C  IF RHO EQUAL 0.  AND TEMP  = 999.  STANDARD ATMOSPHERE IS USED
C  IF RHO EQUALS 0.  AND  TEMP NOT EQUAL 999.  NON STANDARD ATMOSPHERE IS
C   COMPUTED USING TEMP AND PRESS
C
      IF (RHO .NE. 0.0 ) GO TO 40
      IF(TEMP .EQ. 999.)GO TO 35
      TEMP = 1.8*(TEMP + 273.15)
      RHO = .0391462*PRESS/TEMP/32.174
      VC = SQRT(2.923956*PRESS/RHO)
      GO TO 40
   35 HTH = ALT/1000.
      TEMP = 518.68 - .003566*ALT
      RHO = .0023769*( 1.0 + HTH*(-.02875 + .000275*HTH) )
      VC = 49.02*SQRT(TEMP)
C  WING SURFACE DATA
   40 READ(5,100) SW,ALPHWD,ARW,WNGSTA,CLWMXP,CLWMXN
      PRINT 50,DEL0,DEL1,DEL2,CLMAX,A0INCD,A4,A10,MCR0,M1
      PRINT 51,F,FV,RTRSTA,CGSTA,H,GW,CM0,CMALPD,EI,KF,AFD,CL0,XF,N,HT,S
     2HPMAX,TRQPRS,DNWSHK,HPACC,RTRDWK,TE,HE,FUSEMK,THET2P,THET2N
      PRINT 52,ST,ALPH0D,ALPH1D,ALPH2D,ART,TLSTA,CLTMXP,CLTMXN
      PRINT 53,STV,ALPHV0,ARV,VTSTA,HV
      PRINT 54,VT,DMR,B,C,W,WT,E,DEL3D,THETTO
      PRINT 55,VTT,DT,BT,CTR,TRSTA
      PRINT 56,DELVKT,VFIN,ALT,RHO,TEMP,PRESS,VC,THDESD,HRTR
      PRINT 57,SW,ALPHWD,ARW,WNGSTA,CLWMXP,CLWMXN
```

```
      PIE=3.14159
      GWI=GW
      FI=F
      R=DMR/2.
      FIGE = (1. - 1./(1. + 2.667*(HRTR/R)**2))
      RTRDWK = RTRDWK*FIGE
      A=PIE*R*R
      OMEGA=VT/R
      WL=(WNGSTA-CGSTA)/12.
      TTL=(TLSTA-CGSTA)/12.
      TTLV = (VTSTA - CGSTA)/12.0
      LT = (TRSTA - CGSTA)/12.
      Y=(RTRSTA-CGSTA)/12.
      GW=GWI
      V=0.
      VKNOT=0.
      DELV = DELVKT*1.6878
      A0INC=A0INCD*57.3
      AF=AFD*57.3
      CMALP=CMALPD*57.3
      ALPHW=ALPHWD/57.3
      ALPHU=ALPHUD/57.3
      ALPH1=ALPH1D
      ALPH2=ALPH2D*57.3
      ALPHV=ALPHVD/57.3
      ALPHTI=ALPHO
      THDES=THDESD/57.3
      DEL3=DEL3D/57.3
      KBETA=-DEL3
      THETT=THETTD/57.3
      GW=GW*COS(THDES)
      ALPHWI=ALPHW
      CDBAR=.01
      WFAC=(1.+H/SQRT(H*H+R*R))*RTRDWK
      WFACT=(1.+SQRT(H*H+TTL*TTL)/SQRT(H*H+TTL*TTL+R*R))*RTRDWK
      WRITE(6,203) CASE
  347 NCASE=0
C
C  START OF TRIM
C
      DO 500 ICASE=1,10
      ALPHA=-20./57.3
      ALPHA2 = 20./57.3
      NCASE=NCASE+1
      Q=RHO*V**2/2.
      IF(Q.EQ.0.)GO TO 410
      F=FI-GWI*SIN(THDES)/Q
  410 CONTINUE
      AT=5.73*ART/(ART+2.*(ART+4.)/(ART+2.))
      AW=5.73*ARW/(ARW+2.*(ARW+4.)/(ARW+2.))
      ATV=5.73*ARV/(ARV+2.*(ARV+4.)/(ARV+2.))
      DEPDAL=2.*AW/ARW/PIE*DNWSHK
      LV=Q*ATV*ALPHV*STV
      MU=V/VT
      DNOM=0.941-MU**2/2.
      A11=4.*(MU*.941/2.-MU**3/8.)/.941/DNOM
      A12=8.*MU*.97/3./DNOM
```

```
      A13=2.*MU*.941/DNOM
      A14=(.941+1.5*MU**2)/DNOM
      B11=4.*MU*.97/3./(.941+MU**2/2.)
      F1=.304
      F2=.941*(.941+MU**2)/4.
      F3=.913*(.941/5+MU**2/6.)
      F4=MU*.304
      T1=(.941+MU**2/2.)/2.
      T2=.304+.97*MU**2/2.
      T3=.941/4.*(.941+MU**2)
      T4=MU/2.*(.941+MU**2/4.)
      MW=(R-E)**2*W/2.+(R-E)*WT
      IFA=W/3.*(R-E)**3+WT*(R-E)**2
      IFA=IFA/32.2
      TAU=MW/IFA/OMEGA**2
      GAMF=C*RHO*A0INC*R**4/2./IFA
      DO = Q*F
      ACL=A0INC
      CHAY=B*W/32.2*OMEGA**2*E*R*R/4.*(1.+2.*WT/W/R)
      DR=V*B*C*CDBAR*RHO*R*VT/4.
      T = GW*N
      DO 64 IWT = 1,10
      CT=T/A/RHO/VT/VT
      SIG=B*C/PIE/R
      PHI = -DO/T
      WVT=SQRT(.5*(-MU**2+SQRT(MU**4+CT**2)))
      DO 62 JWT = 1,10
      FWVT = WVT**4 - 2.*MU*PHI*WVT**3 + MU**2*WVT**2 - (CT/2.)**2
      DFWVT = 4.*WVT**3 - 6.*MU*PHI*WVT**2 + 2.*MU**2*WVT
      DELWVT = -FWVT/DFWVT
      WVT = WVT + DELWVT
      IF(DELWVT .LT. .05*WVT) GO TO 61
   62 CONTINUE
      PRINT 63
   63 FORMAT(* WT DID NOT CONVERGE*)
   61 CONTINUE
      T = N*(GW + RHO/2.*(WVT*WFAC*VT)**2*FV)
      CT2 = T/A/RHO/VT**2
      IF(ABS(CT2 - CT)/CT .LT. .01) GO TO 65
   64 CONTINUE
   65 TI = T
      DELAT=0.
      DELAW=0.
      IF(MU.EQ.0.)GO TO 411
      DELAT=WVT/MU*(1.+SQRT(H**2+TTL**2)/SQRT(H**2+R**2+TTL**2))*RTRDWK
      DELAT = ATAN(DELAT)
      DELAW=WVT/MU*(1.+SQRT(H**2+WL**2)/SQRT(H**2+WL**2+R**2))*RTRDWK
      DELAW = ATAN(DELAW)
  411 CONTINUE
      ALPHT=ALPHTI-DELAT
      ALPHW=ALPHWI-DELAW
      COUNT=0.
      SWITCH=0.
   23 CLW=AW*(ALPHW+ALPHA)
      IF(CLW.LT.CLWMXN) CLW=CLWMXN*COS(CLW/AW)
      IF(CLW.GT.CLWMXP) CLW=CLWMXP*COS(CLW/AW)
      IF(SWITCH .EQ. 0.0) ALPHT = ALPHO - ALPH1**2/4./ALPH2 - DELAT
```

```
      CLT=AT*(ALPHT+ALPHA-DEPDAL*CLW/AW)
      IF(CLT.LT.CLTMXN)CLT=CLTMXN*COS(CLT/AT)
      IF(CLT.GT.CLTMXP)CLT=CLTMXP*COS(CLT/AT)
      DI=Q*(ST*CLT*CLT/ART+SW*CLW*CLW/ARW)/PIE/.85
      T = TI - Q*(ST*CLT + SW*CLW + R**2*(AF*(ALPHA - DELAW) + CL0))
      D = D0 + DI
      A1=-(ALPHA+(D+DR)/T)
C
C  START OF CONTROL POSITIONS
C
      M=(V+VT)/VC
      LAMDA=MU*ALPHA-MVT
      LAM(ICASE)=LAMDA
      MUF(ICASE)=MU
      THET0=(2.*CT/ACL/SIG-LAMDA*T1)/T2
      BETA0=GAMF*(LAMDA*F1+THET0*F2+THETT*F3)-TAU
      THET1=BETA0*B11+KBETA*A1
      THET2=(A1-LAMDA*A11-(THET0+KBETA*BETA0)*A12-THETT*A13)/A14
      DO 5 I=1,5
      THET0=(2.*CT/ACL/SIG-LAMDA*T1-KBETA*BETA0*T2-THETT*T3-THET2*T4)/T2
      BETA0=GAMF*(LAMDA*F1+THET0*F2+KBETA*BETA0*F2+THETT*F3+THET2*F4)-TA
     1U
      THET1=BETA0*B11+KBETA*A1
      THET2=(A1-LAMDA*A11-(THET0+KBETA*BETA0)*A12-THETT*A13)/A14
      IF(THET2 .LT. THET2N/57.3)THET2 = THET2N/57.3
    5 IF(THET2 .GT. THET2P/57.3)THET2 = THET2P/57.3
      ALPHT=ALPH0+ALPH1*THET2+ALPH2*THET2**2  -DELAT
      CLT=AT*(ALPHT+ALPHA-DEPDAL*CLW/AW)
      IF(CLT.LT.CLTMXN)CLT=CLTMXN*COS(CLT/AT)
      IF(CLT.GT.CLTMXP)CLT=CLTMXP*COS(CLT/AT)
      QV=RHO/2.*(WVT*VT)**2
      MFUSE = QV*R**3*FUSEMK
      MFUSE=MFUSE*WFAC**2
      MTAIL=QV*TTL*ST*1.3
      MTAIL=MTAIL*WFACT**2
      MWING=QV*WL*SW*1.3
      MWING=MWING*WFAC**2
      MTAIL=MTAIL-Q*TTL*ST*CLT
      MWING=MWING-Q*WL*SW*CLW
      MFUSE = MFUSE + Q*R**3*(CM0 + CMALP*(ALPHA - DELAW))- XF*Q*R**2*(A
     1F*(ALPHA - DELAW) + CL0)
      MOMENT=T*A1*H-T*Y+MTAIL+MWING+MFUSE+DR*H+CMAY*A1-ML*TE
C
C  START OF CONVERGENCE SCHEME
C
      IF(SWITCH)21,22,24
   22 MOMNT1=MOMENT
      ALPHA1 = ALPHA
      ALPHA = ALPHA2
      SWITCH = -1.
      GO TO 23
   21 MOMNT2=MOMENT
      KEY = 0
      IF(MOMNT2*MOMNT1 .LE. 0.) GO TO 32
      PRINT 205,ICASE
  205 FORMAT(*  INITIAL ALPHAS DO NOT BRACKET ZERO MOMENT  CCOUNT=*,I2)
      ALPHA = 1.2*ALPHA1
```

```
      ALPHA2 = 1.2*ALPHA2
      SWITCH = 0.0
      GO TO 23
   24 MOMNT3 = MOMENT
      KEY = KEY + 1
      IF(KEY .LT. 3) GO TO 23
      IF(ABS(MOMENT) - GW/500.)26,26,27
   27 IF(MOMNT3*MOMNT2 .GE. 0.) GO TO 28
      ALPHA1 = ALPHA2
      MOMNT1 = MOMNT2
      GO TO 29
   26 MOMNT1 = MOMNT1*MOMNT2/(MOMNT2 + MOMNT3)
   29 ALPHA2 = ALPHA3
      MOMNT2 = MOMNT3
   32 ALPHA3 = MOMNT2*ALPHA1/(MOMNT2 - MOMNT1) + MOMNT1*ALPHA2/(MOMNT1
     1- MOMNT2)
      ALPHA = ALPHA3
      SWITCH=1.
      COUNT=COUNT+1.
      IF(COUNT.GT.50.) GO TO 26
      GO TO 23
   26 CONTINUE
      CCOUNT(ICASE) = COUNT
C
C  START OF POWER CALCULATIONS
C
      PI=(1.+EI)*T*WVT*VT
      CLBAR=6.*CT/SIG
      CDBAR=DEL0+DEL1*CLBAR+DEL2*CLBAR**2
      CPP=SIG*CDBAR/8.
      PP=CPP*RHO*A*VT**3*(1.+KP*MU**2)
      PPAR=D*V
      HPI=PI/550.
      HPP=PP/550.
      HPPAR=PPAR/550.
      P = PI + PP + PPAR
      TT=P/OMEGA/LT-LV*TTLV/LT
      MUT=V/VTT
      AREAT=PIE*DT**2/4.
      CTT=TT/RHO/AREAT/VTT**2
      WVTT=SQRT(.5*(-MUT**2+SQRT(MUT**4+CTT**2)))
      PIT=(1.+EI)*TT*WVTT*VTT
      SIGT=BT*CTR/PIE/DT*2.
      CLBT=6.*CTT/SIGT
      CDBT=DEL0+DEL1*CLBT+DEL2*CLBT**2
      CPPT=SIGT*CDBT/8.
      PPT=CPPT*RHO*AREAT*VTT**3*(1.+KP*MUT**2)
      HPT=(PIT+PPT)/550.
      HP = HPI + HPP + HPPAR + HPT
      GAMMA=CLMAX/A0INC-THET0+THET2-KBETA*BETA0
      BS=A1-MU*THETT-GAMMA
      CS=MU*GAMMA+LAMDA
      IF(BS**2-4.*THETT*CS)7,6,6
    6 XS=(-BS+SQRT(BS**2-4.*THETT*CS))/2./THETT
      X0=-XS-BS/THETT
      IF(XS-1.)900,7,7
  900 IF(XS)7,7,8
```

```
    6 CPS=SIG*(1.-MU)**2*(1.-XS)*SQRT(1.-XS**2)/24./PIE
      IF((X0+XS)/2.-1.)9,10,10
    9 KS=-(BS/2./THETT+XS)/(1.-XS)
      GO TO 11
   10 KS=1.
   11 CPS=KS*CPS
      GO TO 12
    7 CPS=0.
   12 ALP90=KBETA*BETA0+THET0+THET2+THETT+(LAMDA-A1)/(1.+MU)
      A0=A0INC*(1.+A4*M**4+A10*M**10)
      MCRIT=MCR0-M1*A0*ALP90
      IF(MCRIT)13,15,15
   15 IF(M-1.)14,13,13
   13 WRITE(6,200)VKNOT
      GO TO 17
   14 DELMD=M-MCRIT-.06
      IF(DELMD)17,17,16
   16 CPC=SIG*(.012*DELMD+.1*DELMD**3)
      GO TO 18
   17 CPC=0.
   18 HPS=RHO*A*VT**3*CPS/550.
      HPC=RHO*A*VT**3*CPC/550.
      HPTC=HP+HPS+HPC
      P=550.*(HPTC-HPT)
      TT=P/OMEGA/LT-LV*TTLV/LT
      MUT=V/VTT
      AREAT=PIE*DT**2/4.
      CTT=TT/RHO/AREAT/VTT**2
      WVTT=SQRT(.5*(-MUT**2+SQRT(MUT**4+CTT**2)))
      PIT=(1.+EI)*TT*WVTT*VTT
      CLBT=6.*CTT/SIGT
      CDBT=DEL0+DEL1*CLBT+DEL2*CLBT**2
      CPPT=SIGT*CDBT/8.
      PPT=CPPT*RHO*AREAT*VTT**3*(1.+KP*MUT**2)
      HPT=(PIT+PPT)/550.
      HPTC = HPI + HPP + HPPAR + HPT + HPACC + HPS + HPC
      TPRES = HPTC/(.023208*VT)
C
C  PERCENT TORQUE COMPUTATION
C  INPUT DICTATES IF PERCENT TORQUE OR TORQUE PRESSURE IS DESIRED
C
      PCTQ = 100*(1.1*(HPTC - HPT - HPACC) + HPACC)/SHPMAX
      B1=-(TT*HT+LV*HV)/T/H
      PHI=-(TT+LV)/T-B1
      THET1=THET1-B1
      A1=A1*57.3
      ALPHAD=ALPHA*57.3
      BETA0=BETA0*57.3
      THET0=THET0*57.3
      THET1=THET1*57.3
      THET2=THET2*57.3
      PHI=PHI*57.3
      OTPRES(ICASE)=TPRES
      OTPCTQ(ICASE) = PCTQ
      OCLBT(ICASE)=CLBT
      OCLBAR(ICASE)=CLBAR
      OVNOT(ICASE)=VKNOT
```

```
      OVIND(ICASE) = VKNOT*SQRT(RHO/.002377)
      OHPI(ICASE)=HPI
      OHPP(ICASE)=HPP
      OHPPAR(ICASE)=HPPAR
      OHPS(ICASE)=HPS
      OHPC(ICASE)=HPC
      OHPT(ICASE)=HPT
      OHP(ICASE)=HP
      OHPTC(ICASE)=HPTC
      OA1(ICASE)=A1
      OALPHA(ICASE)=ALPHAD
      OBETA0(ICASE)=BETA0
      OTHET0(ICASE)=THETO
      OTHET1(ICASE)=THET1
      OTHET2(ICASE)=THET2
      OPHI(ICASE)=PHI
      OMOMNT(ICASE)=MOMENT
      OALPHT(ICASE)=ALPHT*57.3
      V=V+DELV
      VKNOT = V/1.6878
      IF(VKNOT.GE.VFIN) GO TO 501
  500 CONTINUE
C
C  FINAL OUTPUT SECTION
C
  501 PRINT 701,(OVNOT(I),I=1,NCASE)
      PRINT 750,(OVIND(I),I=1,NCASE)
      PRINT 702,(OHPI(I),I=1,NCASE)
      PRINT 703,(OHPP(I),I=1,NCASE)
      PRINT 704,(OHPPAR(I),I=1,NCASE)
      PRINT 705,(OHPT(I),I=1,NCASE)
      PRINT 706,(OHP(I),I=1,NCASE)
      PRINT 707,(OHPS(I),I=1,NCASE)
      PRINT 708,(OHPC(I),I=1,NCASE)
      PRINT 709,(OHPTC(I),I=1,NCASE)
      PRINT 710,(OA1(I),I=1,NCASE)
      PRINT 711,(OALPHA(I),I=1,NCASE)
      PRINT 712,(OBETA0(I),I=1,NCASE)
      PRINT 713,(OTHET0(I),I=1,NCASE)
      PRINT 714,(OTHET1(I),I=1,NCASE)
      PRINT 715,(OTHET2(I),I=1,NCASE)
      PRINT 716,(OPHI(I),I=1,NCASE)
      PRINT 717,(LAM(I),I=1,NCASE)
      PRINT 718,(MUF(I),I=1,NCASE)
      PRINT 719,(OCLBAR(I),I=1,NCASE)
      PRINT 720,(OCLBT(I),I=1,NCASE)
      PRINT 722,(OTPRES(I),I=1,NCASE)
      PRINT 721,(OTPCTQ(I),I=1,NCASE)
      PRINT 724,(OMOMNT(I),I=1,NCASE)
      PRINT 725,(OALPHT(I),I=1,NCASE)
      PRINT 800,(CCOUNT(I),I=1,NCASE)
      IF(VKNOT.LT.VFIN) GO TO 347
      PRINT 727,F
      STOP
   50 FORMAT(*  DEL0=*,F10.5,*  DEL1=*,F10.5,*  DEL2=*,F10.5,*  CLMAX=*,
     1F10.3,*  A0INCO=*,F10.3,*  A4=*,F10.5,*  A10=*,F10.4,/,*  MCR0=*,F
     210.5,*  M1=*,F10.5)
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```
 51 FORMAT(*  F=*,F10.2,*  FV=*,F10.2,*  RTRSTA=*,F10.2,*  CGSTA=*,F10
   1.2,*  H=*,F10.3,*  GW=*,F10.1/*  CH0=*,F10.6,*  CMALPD=*,F10.6,
   2*  EI=*,F10.3,*  KP=*,F10.2,*  AF0=*,F10.3,*  CL0=*,F10.6,*  XF=*,
   3F10.3/*  N=*,F10.2,*  HT=*,F10.3,*  SHPMAX=*,F10.2,*  TRQPRS=*,
   4F10.1,*  DNWSHK=*,F10.2,*  HPACC=*,F10.1/*  RTROWK=*,F10.1,
   5*  TE=*,F10.1,*  HE=*,F10.2,*  FUSEMK=*,F10.5,*  THET2P=*,F10.2/*
   6 THET2N=*,F10.2)
 52 FORMAT(*  ST=*,F10.2,*  ALPH0D=*,F10.3,*  ALPH1D=*,F10.3,*  ALPH2D
   1=*,F10.3,*  ART=*,F10.2,*  TLSTA=*,F10.2,*  CLTMXP=*,F10.3/*  CLTM
   2XN=*,F10.3)
 53 FORMAT(*  STV=*,F10.2,*  ALPHV0=*,F10.4,*  ARV=*,F10.2,*  VTSTA=*,
   1F10.2,*  HV=*,F10.3)
 54 FORMAT(*  VT=*,F10.2,*  OMR=*,F10.2,*  B=*,F10.0,*  C=*,F10.3,
   1*  W=*,F10.3,*  WT=*,F10.3/*  E=*,F10.3,*  DEL3D=*,F10.3,
   2*  THETT0=*,F10.1)
 55 FORMAT(*  VTT=*,F10.2,*  OT=*,F10.2,*  BT=*,F10.0,*  CTR=*,F10.3,
   1*  TRSTA=*,F10.3)
 56 FORMAT(*  DELVKT=*,F10.1,* VFIN=*,F10.1,* ALT=*,F10.2,* RHO=*,F10.
   16,* TEMP=*,F10.3,* PRESS=*,F10.2/*  VC=*,F10.2,* THDESD=*,F10.2,*
   2MKTR=*,F10.1)
 57 FORMAT(*  SW=*,F10.2,*  ALPHW0=*,F10.2,*  ARW=*,F10.2,*  WNGSTA=*,
   1F10.1,*  CLWMXP=*,F10.3,*  CLWMXN=*,F10.3)
100 FORMAT(8F10.4)
101 FORMAT(20A4)
200 FORMAT( * COMPRESSIBILITY CORRECTION DOUBTFUL  V=*,F5.1,*KNOTS*)
203 FORMAT(//1X,20A4)
701 FORMAT(///* VELOCITY,KNOTS                        *,10F10.1)
702 FORMAT(* MAIN ROTOR INDUCED POWER,HP         *,10F10.1)
703 FORMAT(* MAIN ROTOR PROFILE POWER,HP         *,10F10.1)
704 FORMAT(* MAIN ROTOR PARASITE POWER,HP        *,10F10.1)
705 FORMAT(* TAIL ROTOR POWER,HP                 *,10F10.1)
706 FORMAT(* TOTAL UNCORRECTED POWER,HP.         *,10F10.1)
707 FORMAT(* STALL POWER CORRECTION,HP           *,10F10.1)
708 FORMAT(* COMPRESS POWER CORRECTION,HP        *,10F10.1)
709 FORMAT(* TOTAL CORRECTED POWER,HP            *,10F10.1)
710 FORMAT(* LONGITUDINAL FLAPPING,DEG           *,10F10.2)
711 FORMAT(* DISC PLANE ANGLE-OF-ATTACK,DEG*,10F10.2)
712 FORMAT(* MAIN ROTOR CONING,DEG               *,10F10.2)
713 FORMAT(* MAIN ROTOR COLLECTIVE,DEG           *,10F10.2)
714 FORMAT(* LATERAL CYCLIC PITCH,DEG            *,10F10.2)
715 FORMAT(* LONGITUDINAL CYCLIC PITCH,DEG *,10F10.2)
716 FORMAT(* FUSELAGE ROLL ANGLE,DEG             *,10F10.2)
717 FORMAT(* LAMBDA =                            *,10F10.3)
718 FORMAT(* MU =                                *,10F10.3)
719 FORMAT(* AVG, ROTOR CL                       *,10F10.2)
720 FORMAT(* AVG,TAIL ROTOR CL                   *,10F10.2)
721 FORMAT(* PERCENT TORQUE=                     *,10F10.1)
722 FORMAT(* TORQUE PRESSURE=                    *,10F10.1)
724 FORMAT(* MOMENT UNBALANCE=                   *,10F10.1)
725 FORMAT(* HORIZONTAL TAIL INCIDENCE           *,10F10.1)
727 FORMAT(*  F =  *,F10.4)
750 FORMAT(* INDICATED AIRSPEED,KNOTS            *,10F10.1)
800 FORMAT(* ITERATION COUNT=                    *,10F10.1)
    END
```

APPENDIX B

INPUT GUIDE

INPUT GUIDE

CARD TYPE 1 – FORMAT 20 A4 – RUN NOMENCLATURE

Card No.	Column	Symbol	Description
1	1-80	Case	Title of Run

CARD TYPE 2 – FORMAT 8F10.4 – AIRFOIL DATA

Card No.	Column	Symbol	Description
1	1-10	DELO	Constant term in definition of C_d
	11-20	DEL1	Linear term in definition of C_d
	21-30	DEL2	Quadratic term in definition of C_d
	31-40	CLMAX	Maximum lift coefficient
	41-50	AOINCD	Zero lift line incidence angle (deg)
	51-60	A4	AO = AOINCD (1 $+ A4 \cdot M^4 + A10 \cdot M^{10}$)
	61-70	A10	AO = AOINCD (1 $+ A4 \cdot M^4 + A10 \cdot M^{10}$)
	71-80	MCRO	Critical Mach number for $C_\ell = 0$
2	1-10	M1	Constant in definition of critical Mach number $M_{CRIT} = M_{CRIT_0} - m_1 C_\ell$

CARD TYPE 3 – FORMAT 8F10.4 – FUSELAGE AND GENERAL DATA

Card No.	Column	Symbol	Description
1	1-10	F	Equivalent flat plate area in the horizontal direction (ft^2)

CARD TYPE 3 – FORMAT 8F10.4 – FUSELAGE AND GENERAL DATA (Cont'd)

Card No.	Column	Symbol	Description
1	11-20	FV	Equivalent flat plate area in the vertical direction (ft^2)
	21-30	RTRSTA	Main rotor axis station (in.)
	31-40	CGSTA	Center of gravity station (in.)
	41-50	H	Height of main rotor above cg (ft)
	51-60	GW	Helicopter gross weight (lb)
	61-70	CMO	Fuselage moment coefficient at $\alpha = 0$
	71-80	CMALPD	Slope of fuselage moment coefficient (1/deg)
2	1-10	EI	Fractional increase in rotor induced power above ideal (generally $0.12 \leqslant EI \leqslant 0.15$)
	11-20	KP	Constant in expression for rotor profile power ($P_p = P_{p_0}(1 + KP * \mu^2)$)
	21-30	AFD	Slope of fuselage lift curve (1/deg)
	31-40	CLO	Fuselage lift coefficient at zero angle-of-attack
	41-50	XF	Distance aft of cg where fuselage moment and lift are assumed to be acting
	51-60	N	Load factor = 1 + a/g where a = acceleration in direction of rotor thrust
	61-70	HT	Height of tail rotor above cg (ft)
	71-80	SHPMAX	Value of shaft horsepower corresponding to TRQPRS on torque meter calibration curve (HP)

CARD TYPE 3 – FORMAT 8F10.4 – FUSELAGE AND GENERAL DATA (Cont'd)

Card No.	Column	Symbol	Description
3	1-10	TRQPRS	Reference value of torque meter pressure (preferably the maximum readable on the meter)
	11-20	DNWSHK	Arbitrary correction to downwash at tail due to wing (usually 1.0)
	21-30	HPACC	Horsepower allowed for accessories
	31-40	RTRDWK	Arbitrary correction to downwash at fuselage wing and tail due to main rotor
	41-50	TE	Thrust due to engine exhaust (lb)
	51-60	HE	Height of engine thrust above cg (ft)
	61-70	FUSEMK	Arbitrary correction factor to fuselage moment (normally 1.0)
	71-80	THET2P	Maximum positive value for longitudinal cyclic pitch (deg)
4	1-10	THET2N	Maximum negative value for longitudinal cyclic pitch (deg)

CARD TYPE 4 – FORMAT 8F10.4 – TAIL TRIM SURFACE DATA

Card No.	Column	Symbol	Description
1	1-10	ST	Horizontal tail planform area
	11-20	ALPHOD	Constant, linear, and quadratic terms (deg) in definition of tail incidence

CARD TYPE 4 – FORMAT 8F10.4 – TAIL TRIM SURFACE DATA (Cont'd)

Card No.	Column	Symbol	Description
	21-30	ALPH1D	angle (deg/rad) as a function of longitudinal cyclic pitch (deg/rad^2)
	31-40	ALPH2D	
	41-50	ART	Tail aspect ratio = span/mean chord
	51-60	TLSTA	Station of tail center of pressure (in.)
	61-70	CLTMXP	Maximum tail lift coefficient in the positive (up) direction
	71-80	CLTMXN	Maximum tail lift coefficient in the negative (down) direction

CARD TYPE 5 – FORMAT 8F10.4 – VERTICAL TAIL SURFACE DATA

Card No.	Column	Symbol	Description
1	1-10	STV	Vertical fin planform area (ft^2)
	11-20	ALPHVD	Yaw angle of vertical fin (deg)
	21-30	ARV	Aspect ratio of vertical fin
	31-40	VTSTA	Vertical fin station (in.)
	41-50	HV	Height of vertical fin center of pressure (ft)

CARD TYPE 6 – FORMAT 8F10.4 – MAIN ROTOR DATA

Card No.	Column	Symbol	Description
1	1-10	VT	Rotor tip speed due to rotation (ft/s)
	11-20	DMR	Main rotor diameter (ft)
	21-30	B	Number of main rotor blades

CARD TYPE 6 – FORMAT 8F10.4 – MAIN ROTOR DATA (Cont'd)

Card No.	Column	Symbol	Description
1	31-40	C	Mean chord of main rotor blade (ft)
	41-50	W	Weight of main rotor blade per foot (lb/ft)
	51-60	WT	Main rotor tip weight (lb)
	61-70	E	Flapping hinge offset as a fraction of rotor radius
	71-80	DEL3D	Flapping hinge angle (rate of change of blade pitch with respect to blade flapping)
2	1-10	THETTD	Total blade twist from root to tip (negative for washout)

CARD TYPE 7 – FORMAT 8F10.4 – TAIL ROTOR DATA

Card No.	Column	Symbol	Description
1	1-10	VTT	Tail rotor tip speed due to rotation (ft/s)
	11-20	DT	Tail rotor diameter (ft)
	21-30	BT	Number of tail rotor blades
	31-40	CTR	Mean blade chord of tail rotor blade (ft)
	41-50	TRSTA	Tail rotor station (in.)

CARD TYPE 8 – FORMAT 8F10.4 – OPERATING CONDITIONS

Card No.	Column	Symbol	Description
1	1-10	DELVKT	Velocity increment (kn)
	11-20	VFIN	Velocity which is a small increment above final velocity to be considered

CARD TYPE 8 – FORMAT 8F10.4 – OPERATING CONDITIONS (Cont'd)

Card No.	Column	Symbol	Description
1	21-30	ALT	Altitude (ft)
	31-40	RHO	Air density (slugs/ft^3) Note: RHO ≠ 0, density and VC are input. RHO = 0, and TEMP = 999.0, standard atmosphere is used. RHO = 0, and TEMP ≠ 999.0, nonstandard atmosphere is computed using temperature and pressure.
	41-50	TEMP	Temperature (°C)
	51-60	PRESS	Pressure (mb)
	61-70	VC	Speed of sound (ft/s)
	71-80	THDESD	Aircraft descent angle (negative if ascending) (deg)
2	1-10	HRTR	Height of rotor above ground. Note: HRTR determines a correction for inground effect (IGE) flight. If HRTR > ~ 50, no correction is made and magnitude of HRTR is unimportant.

CARD TYPE 9 – FORMAT 8F10.4 – WING SURFACE DATA

Card No.	Column	Symbol	Description
1	1-10	SW	Wing planform area (ft^2)
	11-20	ALPHWD	Wing incidence angle (deg)
	21-30	ARW	Wing aspect ratio
	31-40	WNGSTA	Wing station (in.)
	41-50	CLWMXP	Maximum wing coefficient of lift in the postive (up) direction
	51-60	CLWMXN	Maximum wing coefficient of lift in the negative (down) direction

APPENDIX C

SAMPLE OUTPUT

TRIAL DATA RUN LEVEL FLIGHT

VELOCITY,KNOTS	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
INDICATED AIRSPEED,KNOTS	0.0	10.0	20.0	29.9	39.9	49.9	59.9	69.8	79.8	89.8
MAIN ROTOR INDUCED POWER,HP	739.1	701.7	598.0	478.1	379.6	309.0	258.6	221.6	193.5	171.5
MAIN ROTOR PROFILE POWER,HP	217.3	217.5	217.8	219.5	221.9	225.0	228.7	233.1	238.2	244.0
MAIN ROTOR PARASITE POWER,HP	0.0	-2.2	-3.0	-1.7	3.0	12.6	28.2	50.9	81.9	122.2
TAIL ROTOR POWER,HP	71.3	66.1	52.9	39.3	30.3	25.7	23.5	22.7	23.0	23.9
TOTAL UNCORRECTED POWER,HP	1027.7	983.1	865.8	735.2	634.9	572.2	539.0	528.2	535.9	560.4
STALL POWER CORRECTION,HP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPRESS POWER CORRECTION,HP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	30.5	56.1
TOTAL CORRECTED POWER,HP	1052.7	1008.1	890.8	760.2	659.9	597.2	564.0	559.4	592.1	642.7
LONGITUDINAL FLAPPING,DEG	2.86	2.85	2.73	2.62	2.46	2.24	1.96	1.64	1.28	.89
DISC PLANE ANGLE-OF-ATTACK,DEG	-2.80	-2.47	-2.53	-2.64	-2.78	-2.95	-3.15	-3.38	-3.66	-3.98
MAIN ROTOR CONING,DEG	2.66	2.64	2.58	2.53	2.49	2.46	2.44	2.43	2.42	2.42
MAIN ROTOR COLLECTIVE,DEG	16.66	16.42	15.77	15.11	14.62	14.33	14.22	14.26	14.42	14.71
LATERAL CYCLIC PITCH,DEG	2.11	2.11	1.96	1.70	1.65	1.60	1.61	1.60	1.82	2.01
LONGITUDINAL CYCLIC PITCH,DEG	2.80	2.40	1.88	1.42	.92	.37	-.25	-.94	-1.69	-2.52
FUSELAGE ROLL ANGLE,DEG	-1.27	-1.22	-1.08	-.93	-.81	-.73	-.69	-.69	-.74	-.81
LAMBDA =	-.050	-.048	-.042	-.035	-.030	-.027	-.025	-.025	-.025	-.026
MU =	0.000	.023	.046	.069	.091	.114	.137	.160	.183	.206
AVG, ROTOR CL	.45	.45	.45	.45	.45	.45	.45	.45	.45	.45
AVG,TAIL ROTOR CL	.33	.31	.28	.24	.21	.19	.18	17	.19	.20
TORQUE PRESSURE=	61.4	58.8	52.0	44.4	38.5	34.9	32.9	32.7	34.6	37.5
PERCENT TORQUE=	83.5	80.1	71.3	61.3	53.5	48.5	45.9	45.6	48.3	52.6
MOMENT UNBALANCE=	-.0	.2	.3	.2	.4	1.5	3.6	4.3	1.2	-14.9
HORIZONTAL TAIL INCIDENCE	1.4	-54.9	-31.1	-17.4	-10.0	-6.0	-3.6	-2.0	-.9	.1
ITERATION COUNT=	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

VELOCITY,KNOTS	100.0	110.0	120.0	130.0	140.0	150.0	160.0	170.0
INDICATED AIRSPEED,KNOTS	99.8	109.7	119.7	129.7	139.7	149.6	159.6	169.6
MAIN ROTOR INDUCED POWER,HP	153.0	139.4	127.4	117.4	109.1	101.9	95.9	91.0
MAIN ROTOR PROFILE POWER,HP	250.4	257.6	265.4	273.9	283.0	292.9	303.4	314.6
MAIN ROTOR PARASITE POWER,HP	172.8	234.9	309.4	397.3	499.5	616.5	750.0	901.2
TAIL ROTOR POWER,HP	25.3	27.1	29.5	32.6	36.5	41.3	47.4	55.0
TOTAL UNCORRECTED POWER,HP	600.4	656.4	728.2	816.6	922.1	1044.9	1196.8	1349.0
STALL POWER CORRECTION,HP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPRESS POWER CORRECTION,HP	83.3	112.2	143.4	177.3	214.6	256.4	303.9	359.0
TOTAL CORRECTED POWER,HP	710.6	796.2	900.1	1023.4	1167.6	1334.0	1525.5	1745.8
LONGITUDINAL FLAPPING,DEG	.51	.13	-.23	-.53	-.76	-.92	-.95	-.86
DISC PLANE ANGLE-OF-ATTACK,DEG	-4.40	-4.89	-5.48	-6.18	-7.03	-7.99	-9.11	-10.30
MAIN ROTOR CONING,DEG	2.43	2.44	2.46	2.48	2.52	2.57	2.63	2.70
MAIN ROTOR COLLECTIVE,DEG	15.12	15.66	16.33	17.13	18.08	19.18	20.41	21.79
LATERAL CYCLIC PITCH,DEG	2.24	2.51	2.82	3.18	3.58	4.04	4.54	5.10
LONGITUDINAL CYCLIC PITCH,DEG	-3.38	-4.30	-5.26	-6.26	-7.26	-8.30	-9.32	-10.33
FUSELAGE ROLL ANGLE,DEG	-.90	-1.02	-1.16	-1.33	-1.52	-1.74	-1.99	-2.26
LAMBDA =	-.028	-.031	-.035	-.040	-.047	-.055	-.065	-.077
MU =	.229	.251	.274	.297	.320	.343	.366	.389
AVG, ROTOR CL	.45	.45	.45	.45	.45	.45	.45	.45
AVG,TAIL ROTOR CL	.32	.25	.29	.33	.38	.43	.49	.57
TORQUE PRESSURE=	41.5	46.5	52.5	59.7	68.2	77.9	89.0	101.9
PERCENT TORQUE=	58.2	65.4	74.0	84.3	96.3	110.0	125.9	144.0
MOMENT UNBALANCE=	2.4	1.1	-.6	-.5	19.0	-11.0	-12.3	-17.7
HORIZONTAL TAIL INCIDENCE	.9	1.7	2.5	3.3	4.2	5.2	6.2	7.2
ITERATION COUNT=	3.0	3.0	3.0	3.0	3.0	4.0	5.0	5.0

F = 17.5961

APPENDIX D

COMPARISON WITH FLIGHT-TEST DATA

COMPARISON WITH FLIGHT-TEST DATA

Because of inconsistencies and gaps in existing angle-of-attack information, a flight-test program was undertaken to validate this model. An AH1-J aircraft was instrumented and tests flown at the Naval Air Test Center, Patuxent River, Maryland. Data was required for level and descending trimmed flight, with forward and aft center-of-gravity locations, in-ground and out-of-ground effects, throughout the speed regime of the aircraft. Both standard and combat load and clean-configured aircraft were used.

Figures D-1 through D-6 present data that was obtained in a few of the early phases of these tests. While a model is never truly complete as long as adjustments and "fine tuning" are still going on, these figures are presented to show the agreement of the model with test data at this point in time. Areas presented include angle-of-attack, shaft horsepower, and longitudinal cyclic pitch versus forward velocity for a number of flights. Flight test angle-of-attack and longitudinal cyclic pitch are believed to be accurate within ±0.5° (due to instrumentation accuracy).

The objective of low cost data has been met quite easily since the average amount of computer time per data point is 0.03 s.

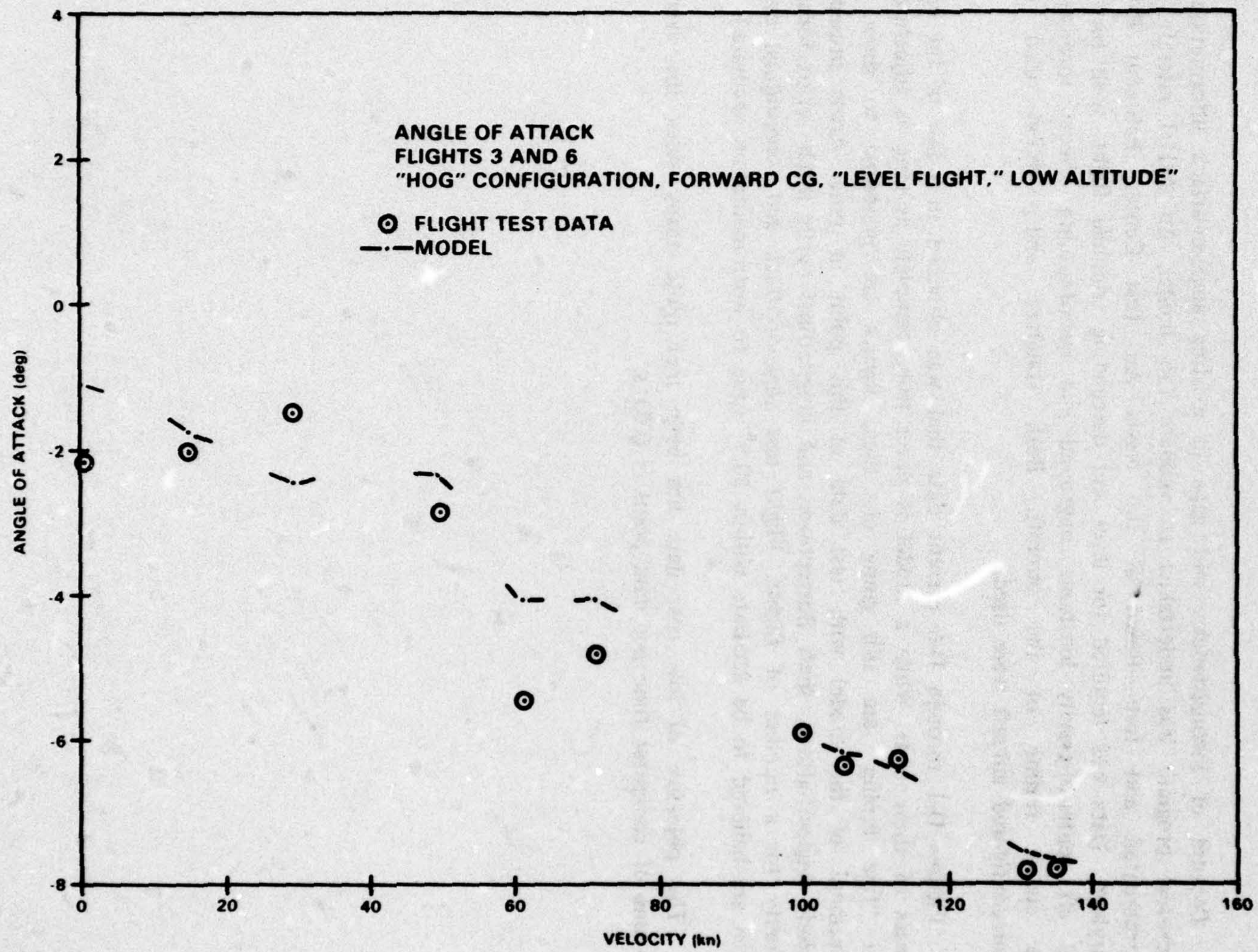

Figure D-1. Angle of Attack Versus Velocity – Flights 3 and 6

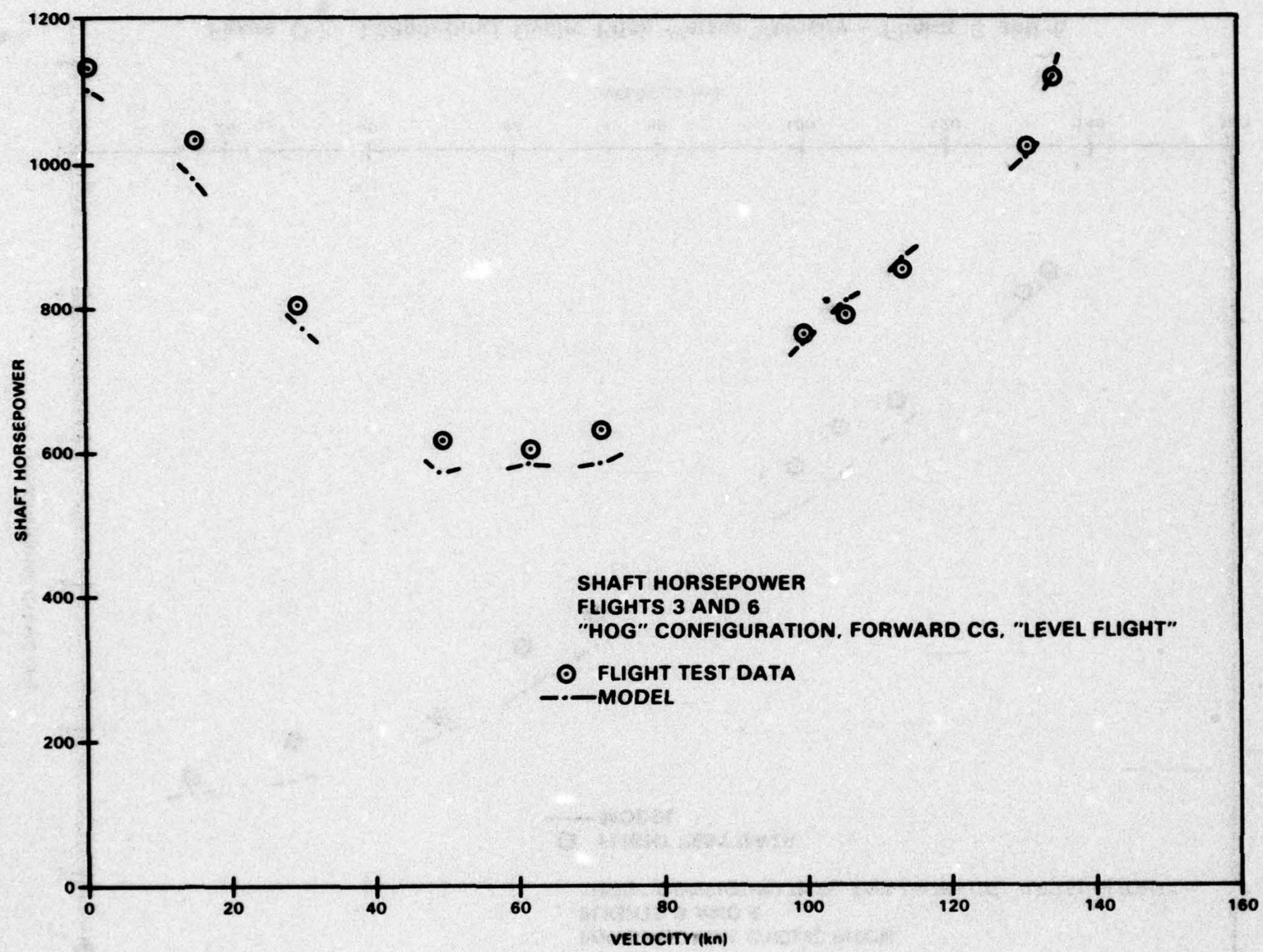

Figure D-2. Horsepower Versus Velocity – Flights 3 and 6

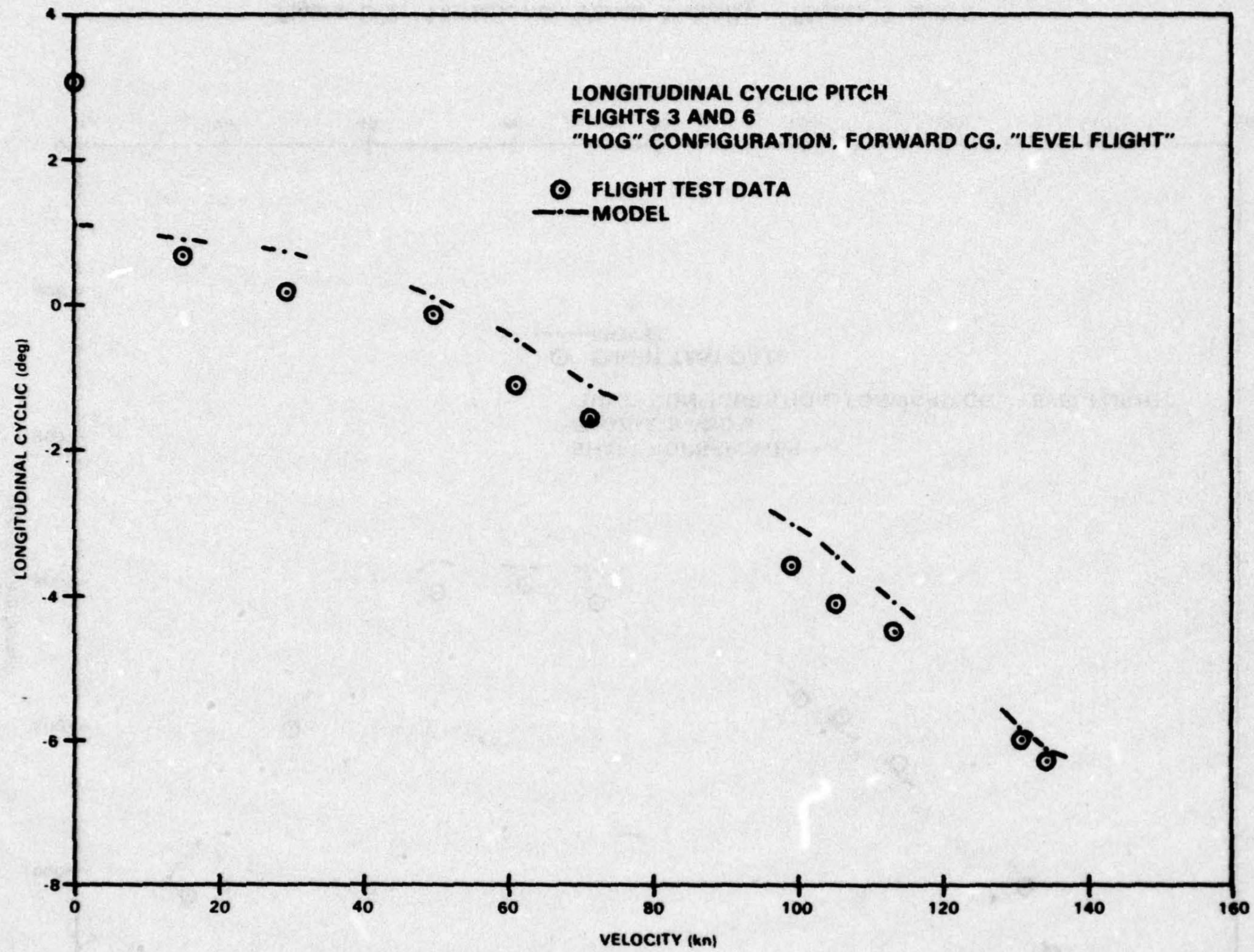

Figure D-3. Longitudinal Cyclic Pitch Versus Velocity – Flights 3 and 6

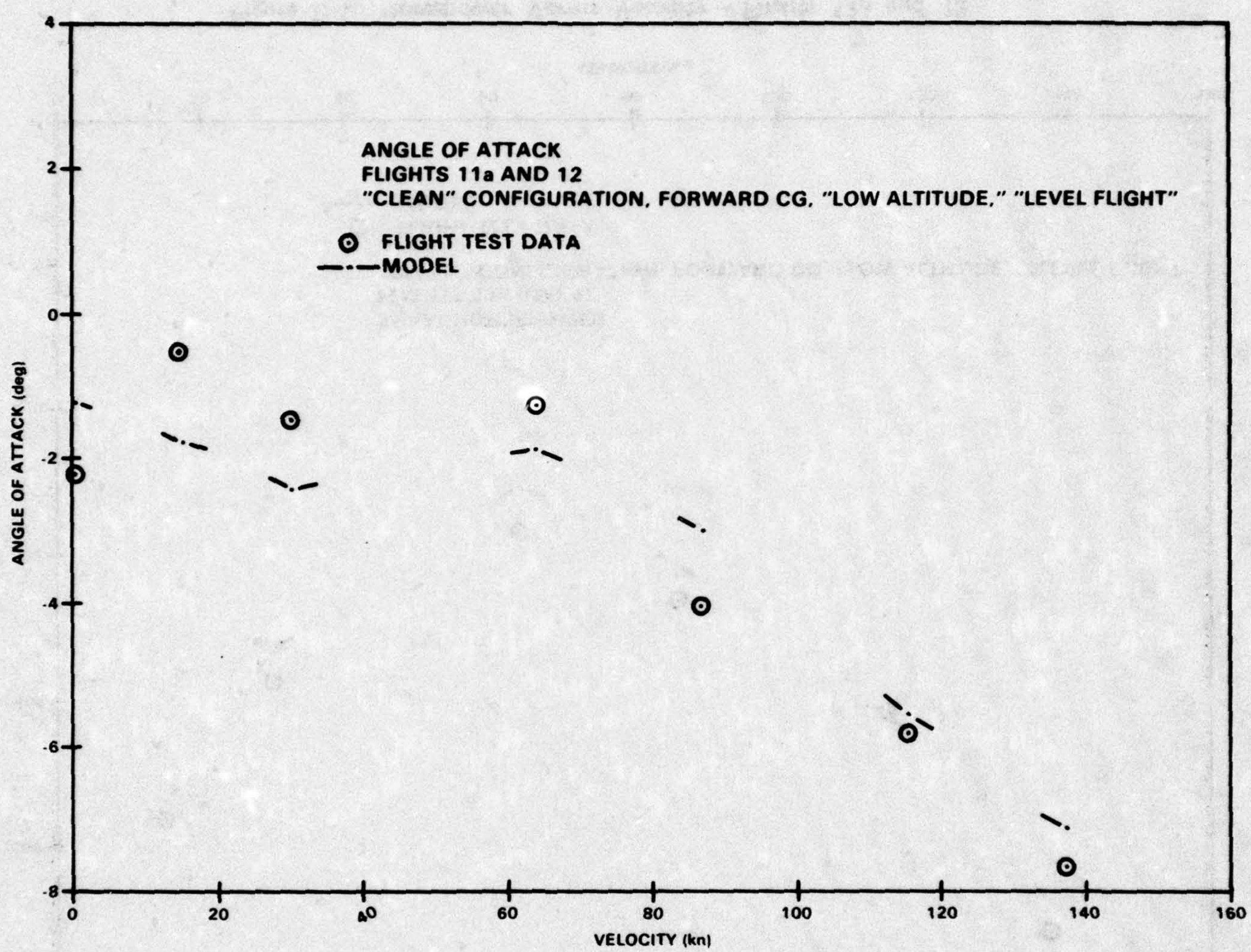

Figure D-4. Angle of Attack Versus Velocity – Flights 11a and 12

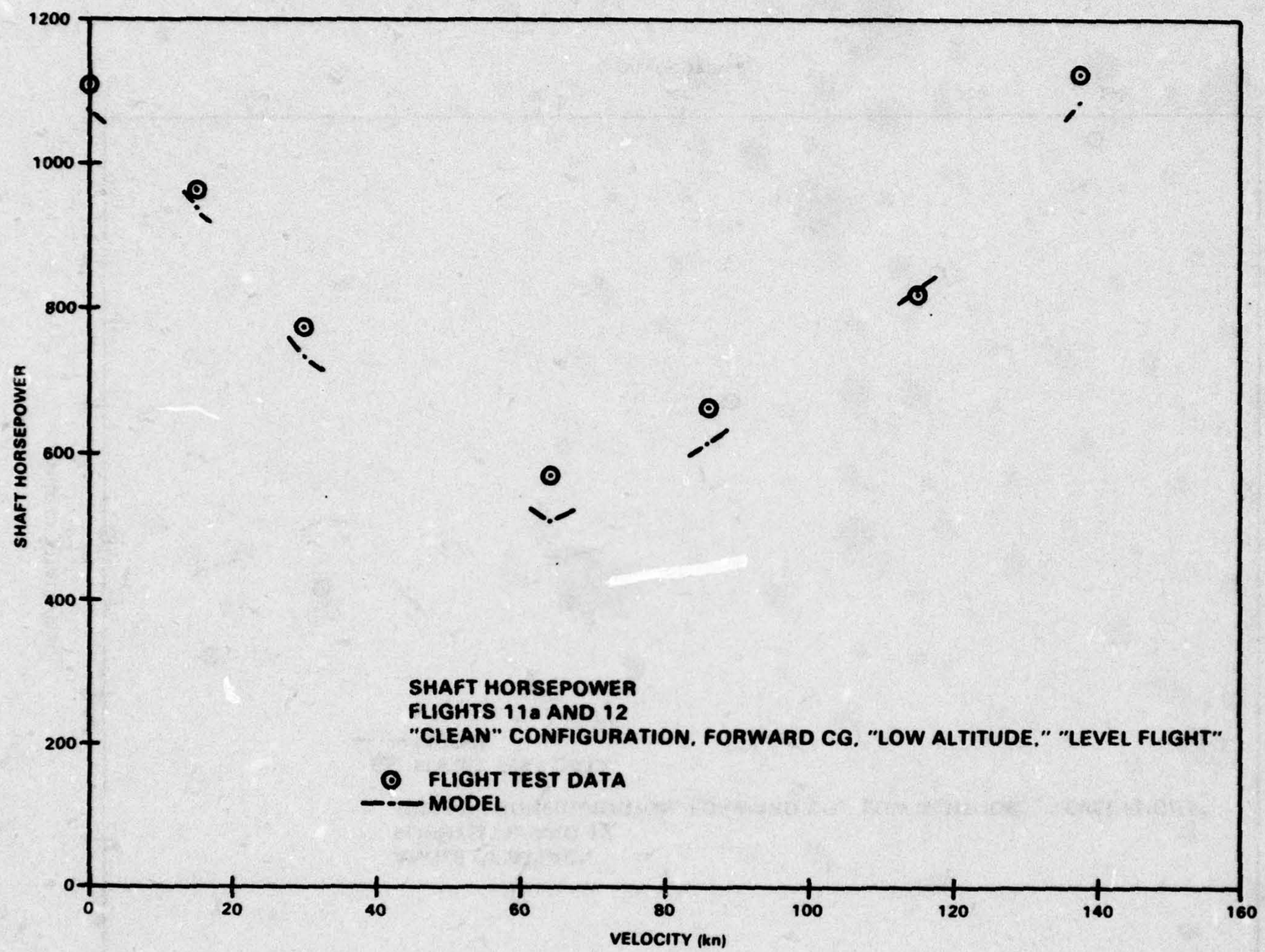

Figure D-5. Horsepower Versus Velocity – Flights 11a and 12

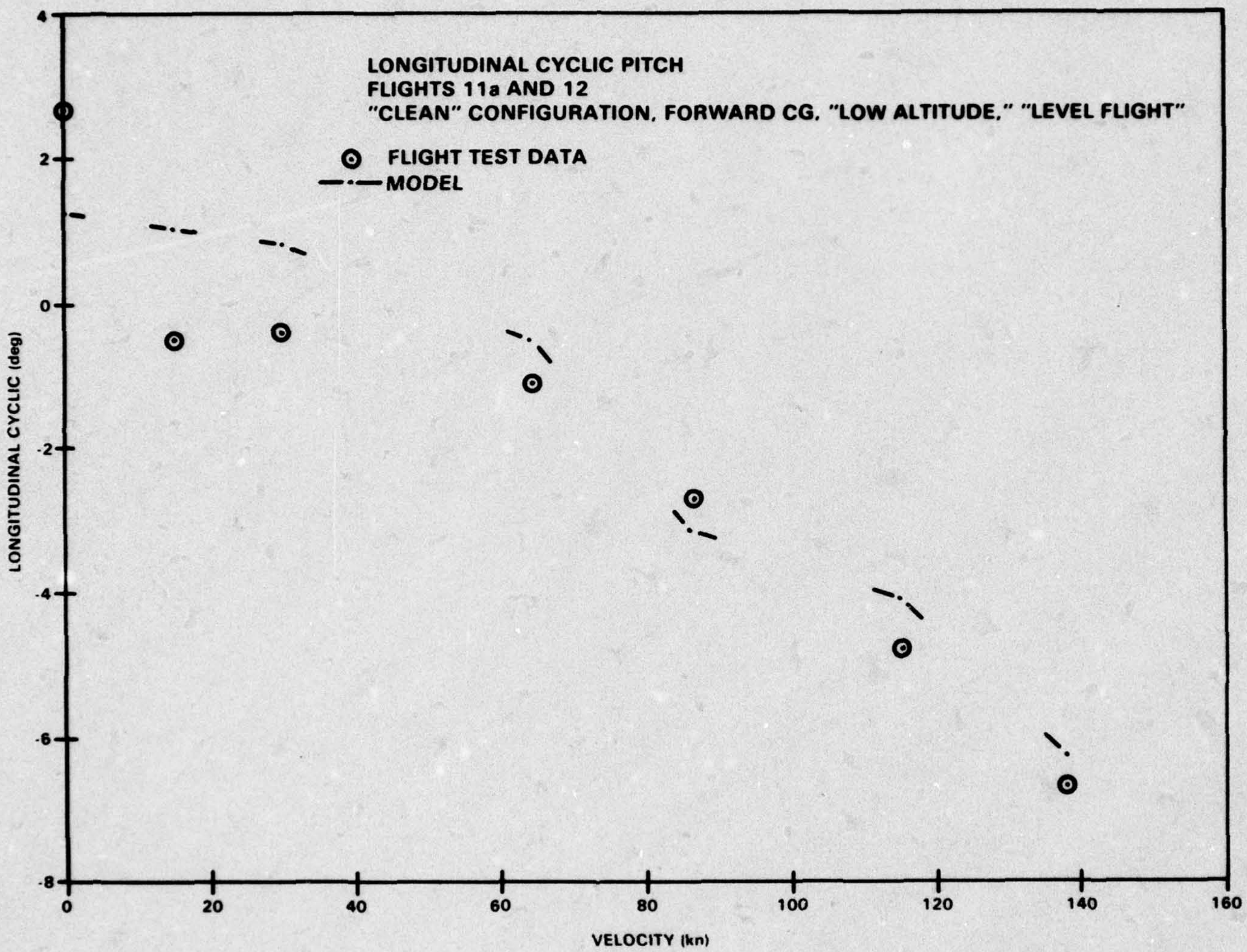

Figure D-6. Longitudinal Cyclic Pitch Versus Velocity – Flights 11a and 12

APPENDIX E

NOMENCLATURE

NOMENCLATURE

Term	Mnemonic	Definition	Units
A	A	Rotor disk area = πR^2	ft^2
	ACL	Slope of airfoil section lift curve = $dC_\ell/d\alpha$ for M = 0	1/rad
	AF	Slope of fuselage lift curve	1/rad
α	ALPHA	Disk plane angle of attack	rad
α_{max}		Angle of attack corresponding to $C_{\ell_{max}}$	rad
α_T	ALPHT	Angle of attack of the horizontal stabilizer	rad
α_V	ALPHV	Yaw angle of the vertical fin	rad
α_W	ALPHW	Wing incidence angle	rad
α_{0D}	ALPHOD	Constant term in equation defining tail incidence as a function of longitudinal cyclic pitch	deg
α_{1D}	ALPH1D	Linear term in tail incidence equation	deg/rad
α_{2D}	ALPH2D	Quadratic term in tail incidence equation	deg/rad^2

Term	Mnemonic	Definition	Units
α_{90}	ALP90	Angle of attack of the advancing blade at $\psi = 90°$	rad
	AREAT	Tail-rotor disk area = $1/4\ \pi D_t^2$	ft^2
AR		Aspect ratio for rotor	dimensionless
AR_t	ART	Horizontal stabilizer aspect ratio = span/mean chord	dimensionless
AR_V	ARV	Vertical fin aspect ratio	dimensionless
AR_W	ARW	Wing aspect ratio	dimensionless
	AT	$dC_L/d\alpha$ for the horizontal tail	1/rad
	ATV	$dC_L/d\alpha$ for the vertical tail	1/rad
	AW	$dC_L/d\alpha$ for the wing	1/rad
	AO	Slope of section lift curve (function of local Mach number) for A_0 lift line	dimensionless
$a_{0_{inc}}$	AOINC	Incidence angle of zero lift line	rad
a_1	A1	Longitudinal flapping	rad

Term	Mnemonic	Definition	Units
a_4	A4	Term in equation defining AO in terms of Mach and AOINC AO = AOINC $(1 + A4 \cdot M^4 + A10 \cdot M^{10})$	dimensionless
a_{10}	A10	Term in equation defining A0	dimensionless
A11	A11	Term in definition of THET2 $A11 = \dfrac{4(\mu B_0^2/2 - \mu 3/8)}{B_0^2(B_0^2 - \mu^2/2)}$	dimensionless
A12	A12	Term in definition of THET2 $A12 = \dfrac{8\mu B_0}{3(B_0^2 - \mu^2/2)}$	dimensionless
A13	A13	Term in definition of THET2 $A13 = \dfrac{2\mu B_0^2}{B_0^2 - \mu^2/2}$	dimensionless
A14	A14	Term in definition of THET2 $A14 = \dfrac{B_0^2 + 3\mu^2/2}{B_0^2 - \mu^2/2}$	dimensionless
B	B	Number of blades on main rotor	dimensionless
β_0	BETAO	Main rotor coning angle	rad
B_s	BS	Term in definition of X_s $B_s = a_1 - \mu\theta_T - \Gamma$	dimensionless

Term	Mnemonic	Definition	Units
B_t	BT	Number of blades on tail rotor	dimensionless
B_0		Effective dimensionless main rotor radius (accounts for loss of thrust toward blade tips)	dimensionless
b_1	B1	Lateral flapping	rad
B11	B11	Term in definition of lateral flapping (θ_1) $B11 = \dfrac{4\mu B_0}{3(B_0^2 + 1/2\,\mu^2)}$	dimensionless
C	C	Mean chord of main rotor blade	ft
	CASE	ALPHANUMERIC TITLE OF RUN (up to 80 characters)	dimensionless
	CCOUNT	Internal counting array	dimensionless
$\overline{C_d}$	CDBAR	Estimate of coefficient of drag (main rotor)	dimensionless
$\overline{C_d}_t$	CDBT	$\overline{C_d}$ for the tail	dimensionless
CG_{STA}	CGSTA	Center of gravity station	in.

Term	Mnemonic	Definition	Units
k	CHAY	Ratio of rotor hub moment to a_1 due to hinge offset $k = \frac{B \cdot W}{32.2} w^2 \cdot e \cdot \frac{R^2}{4} \left(1 + \frac{2W_T}{W \cdot R}\right)$	ft-lb/rad
$\overline{C}_\ell$	CLBAR	Average main rotor coefficient of lift (C_ℓ)	dimensionless
$\overline{C}_{\ell_t}$	CLBT	Average tail rotor coefficient of lift	dimensionless
$C_{\ell_{max}}$	CLMAX	Maximum coefficient of lift	dimensionless
C_{ℓ_t}	CLT	Tail lift coefficient	dimensionless
$C_{\ell_{tmaxn}}$	CLTMXN	Maximum C_{ℓ_t} in the negative (down) direction	dimensionless
$C_{\ell_{tmaxp}}$	CLTMXP	Maximum C_{ℓ_t} in the positive (up) direction	dimensionless
C_{ℓ_W}	CLW	Wing lift coefficient	dimensionless
$C_{\ell_{Wmaxn}}$	CLWMXN	Maximum C_{ℓ_W} in the negative (down) direction	dimensionless
$C_{\ell_{Wmaxp}}$	CLWMXP	Maximum C_{ℓ_W} in the positive (up) direction	dimensionless
C_{ℓ_0}	CLO	Fuselage lift coefficient at zero angle of attack	dimensionless
	CMALP	Slope of fuselage moment coefficient	1/rad

Term	Mnemonic	Definition	Units
	CMO	Fuselage moment coefficient at $\alpha = 0$	dimensionless
	COUNT	Internal counter for convergence scheme	dimensionless
C_P		Power coefficient	dimensionless
C_{P_c}	CPC	Correction to power coefficient due to compressibility	dimensionless
C_{P_p}	CPP	Profile power coefficient (main rotor)	dimensionless
$C_{P_{pt}}$	CPPT	Profile power coefficient (tail rotor)	dimensionless
C_{P_s}	CPS	Correction to power coefficient due to stall	dimensionless
C_s	CS	Term in definition of X_s $C_s = \mu\Gamma + \lambda$	dimensionless
C_T	CT	Coefficient of thrust main rotor	dimensionless
C_{TR}	CTR	Mean blade chord tail rotor	dimensionless
C_{TT}	CTT	Coefficient of thrust-tail rotor	dimensionless
D	D	Drag	lb

Term	Mnemonic	Definition	Units
δ_{α_T}	DELAT	Change in tail angle of attack due to downwash	rad
δ_{α_W}	DELAW	Change in wing angle of attack due to downwash	rad
ΔMd	DELMD	Term in definition of C_{P_c} $\Delta Md = M - M_{CRIT} - 0.06$	dimensionless
δV	DELV	Velocity increment	ft/s
δV_{KT}	DELVKT	Velocity increment	kn
δ_{WVT}	DELWVT	FWVT/DFWVT (used in convergence scheme for WVT)	dimensionless
δ_0	DEL0	Term in definition of C_d (input)	dimensionless
δ_1	DEL1	Term in definition of C_d (input)	dimensionless
δ_2	DEL2	Term in definition of C_d (input)	dimensionless
δ_3	DEL3	Rate of change of blade pitch with respect to blade flapping (flapping hinge angle)	dimensionless
$d\epsilon/d\alpha$	DEPDAL	Rate of change of downwash angle at tail with change in wing angle of attack	dimensionless
$d(f(WVT))$	DFWVT	Derivative of FWVT	dimensionless
D_I	DI	Induced drag	lb
D_{MR}	DMR	Main rotor diameter	ft

Term	Mnemonic	Definition	Units
D_{MR} (Cont'd)	DNOM	Intermediate term in calculation of A11 - A14	dimensionless
DNWSHK	DNWSHK	Arbitrary correction to downwash at tail due to wing (normally 1)	dimensionless
D_R	DR	Main rotor drag	lb
D_t	DT	Tail rotor diameter	ft
D_0	DO	Drag due to dynamic pressure and flat plate area	lb
e	E	Flapping hinge offset as a fraction of rotor radius	dimensionless
EI	EI	Fractional increase in rotor-induced power above ideal ($P_i = P_{i_{ideal}}(1 + EI)$)	dimensionless
f	F	Equivalent flat plate area in the horizontal direction	ft^2
F_{IGE}	FIGE	Correction to account for operation in ground effect	dimensionless
	FUSEMK	Arbitrary correction factor to fuselage moment	dimensionless
fV	FV	Equivalent flat plate area in the vertical direction (adjusted to match power at hover)	ft^2
f(WVT)	FWVT	Function of WVT	dimensionless

Term	Mnemonic	Definition	Units
F_1	F1	Term in definition of coning angle $F_1 = \frac{B_0^3}{3}$	dimensionless
F_2	F2	Term in definition of coning angle $F_2 = 1/4\, B_0^2(B_0^2 + \mu^2)$	dimensionless
F_3	F3	Term in definition of coning angle $F_3 = B_0^3(1/5\, B_0^2 + 1/6\, \mu^2)$	dimensionless
F_4	F4	Term in definition of coning angle $F_4 = 1/3\, \mu B_0^3$	dimensionless
γ_F	GAMF	Term in definition of coning angle (lock number) $\gamma_F = \frac{C\rho a_{0_{inc}} R^4}{2\Gamma_F}$	dimensionless
Γ	GAMMA	Term in difinition of B_s and C_s $\Gamma = \alpha_{max} - \theta_0 + \theta_2 - K_\beta \cdot \beta_0$	dimensionless
GW	GW	Aircraft gross weight (input) internally modified to indicate component of weight perpendicular to flight path	lb
GW_I	GWI	Aircraft gross weight	lb
H	H	Height of main rotor above center of gravity (cg)	ft

Term	Mnemonic	Definition	Units
HE	HE	Height of engine thrust above cg	ft
HP	HP	Total uncorrected horsepower	hp
HP_{ACC}	HPACC	Accessory horsepower	hp
HP_c	HPC	Compressibility power correction	hp
HP_I	HPI	Main rotor induced power	hp
HP_p	HPP	Main rotor profile power	hp
HP_{PAR}	HPPAR	Main rotor parasite power	hp
HP_s	HPS	Stall power correction	hp
HP_t	HPT	Tail rotor power	hp
HP_{TC}	HPTC	Total corrected power, i.e., HP corrected for accessories, stall, and compressibility effects	hp
H_{RTR}	HRTR	Height of main rotor above the ground	ft
HT	HT	Height of tail rotor above cg	ft
HV	HV	Height of vertical fin center of pressure above cg	ft
I_F	IFA	Blade moment of inertia about flapping axis	$lb\text{-}ft^2$

Term	Mnemonic	Definition	Units
K_β	KBETA	$d\theta/d\beta = \delta_3$ effect	dimensionless
KP	KP	Constant in expression for rotor profile power $P_P = P_{P_0}(1 + KP \cdot \mu^2)$ where P_{P_0} = profile power in hover	dimensionless
K_s	KS	Factor which varies stall correction	dimensionless

$$K_s = \begin{cases} -\left(\dfrac{B_s/2\theta_T + X_s}{1 - X_s}\right) & \text{for } \dfrac{-B_s}{2\theta_T} < 1 \\ 1 & \text{for } \dfrac{-B_s}{2\theta_T} \geqslant 1 \end{cases}$$

Term	Mnemonic	Definition	Units
L		Fuselage lift	lb
L_t		Lift at tail	lb
λ	LAMDA	Ratio of the net velocity up through the disc plane to the tip speed $\lambda = V_\alpha - w/V_T$	dimensionless
ℓ_t	LT	Horizontal distance from tail rotor to cg	ft
ℓ_v	LV	Distance of vertical tail center of pressure from cg	ft
M	M	Mach number	dimensionless
m		Moment	ft-lb
M_{CRIT}	MCRIT	Critical Mach number of advancing blade at ψ (azimuth) = 90°	dimensionless

Term	Mnemonic	Definition	Units
M_{CRIT_0}	MCRO	Critical Mach number for $C_\ell = 0$	dimensionless
M_{FUSE}	MFUSE	Moment due to the fuselage	ft-lb
MOMENT	MOMENT	MOMENT unbalance (total moment about cg)	ft-lb
$MOMENT_{1(2,3)}$	MOMNT1(2,3)	Measures of moments at different angles of attack (used in convergence scheme)	ft-lb
M_{TAIL}	MTAIL	Moment due to tail	ft-lb
μ	MU	Main rotor advance ratio (ratio of forward velocity to rotor tip speed V_T)	dimensionless
μ_t	MVT	Advance ratio for tail rotor	dimensionless
M_T		Tip Mach number	dimensionless
M_W	MW	Moment about the flapping axis due to rotor weight	ft-lb
M_{WING}	M_{WING}	Moment due to wing	ft-lb
m_1	M1	Constant in definition of critical Mach number $M_{CRIT} = M_{CRIT_0} - m_1 C_\ell$	dimensionless
n	N	Load factor = 1 + a/g where a = acceleration in direction of rotor thrust	dimensionless

Term	Mnemonic	Definition	Units
Ω	OMEGA	Rotational velocity	rad/s
P	P	Power	ft-lb/s
%Q	PCTQ	Percent torque	dimensionless
ϕ	PHI	Fuselage roll angle	rad
P_i	PI	Rotor induced power	ft-lb/s
π	PIE	3.14159	dimensionless
P_{i_t}	PIT	Tail rotor induced power	ft-lb/s
P_P	PP	Main rotor profile power	ft-lb/s
P_{PAR}	PPAR	Main rotor parasite power	ft-lb/s
P_{P_0}		Profile power required in hover	hp
P_{P_t}	PP_T	Tail rotor profile power	ft-lb/s
	PRESS	Air pressure at operating altitude	mb
ψ		Main rotor azimuth angle	deg
Q	Q	Dynamic pressure $Q = 1/2\, \rho V^2$	lb/ft^2
Q_v	QV	Dynamic pressure in the vertical sense $Q_V = 1/2\, \rho\, w^2$ where w = downwash velocity at rotor	lb/ft^2

Term	Mnemonic	Definition	Units
R	R	Main rotor radius	ft
ρ	RHO	Air density	$slug/ft^3$
RTR_{DWK}	RTRDWK	Rotor downwash constant arbitrarily varies downwash from rotor acting on fuselage wing and tail $RTR_{DWK} > 1 \rightarrow$ increase in downwash and vice versa	dimensionless
RTR_{STA}	RTRSTA	Main rotor axis station	in.
S	S	Area	ft^2
SHP_{max}	SHPMAX	Value of shaft horsepower corresponding to TRQPRS on torque pressure (%Q) calibration curve	hp
σ	SIG	Main rotor solidity $SIG = \frac{BC}{\pi R}$	dimensionless
σ_t	SIGT	Tail rotor solidity $SIG = \frac{2BC}{\pi D_t}$	dimensionless
S_t	ST	Horizontal tail planform area	ft^2
S_{t_v}	STV	Vertical fin planform area	ft^2

Term	Mnemonic	Definition	Units
S_W	SW	Planform area of the wing	ft^2
T	T	Main rotor thrust	lb
τ	TAU	Term in definition of β_0 $\tau = \frac{M_W}{I_F w^2}$	dimensionless
TE	TE	Thrust due to engine exhaust	lb
	TEMP	Air temperature at operating aititude	°C
θ		Pitch angle	deg
θ_D	THDES	Aircraft descent angle (negative if ascending)	rad
θ_T	THETT	Total blade twist from root to tip (negative for washout)	deg
θ_0	THETO	Main rotor collective pitch	rad
θ_1	THET1	Main rotor lateral cyclic pitch	rad
θ_2	THET2	Main rotor longitudinal cyclic pitch	rad
θ_{2-}	THET2N	Maximum negative value for longitudinal cyclic pitch	deg
θ_{2+}	THET2P	Maximum positive value for longitudinal cyclic pitch	deg

Term	Mnemonic	Definition	Units
T_I	TI	Initial main rotor thrust estimate	lb
TL_{STA}	TLSTA	Station of tail center of pressure	in.
TR_{STA}	TRSTA	Tail rotor station	in.
T_t	TT	Tail rotor thrust	lb
TT_ℓ	TTL	Distance from cg to tail station center of pressure	ft
$TT_{\ell v}$	TTLV	Distance from cg to vertical fin station	ft
T_1	T1	Term in definition of θ_0 $T_1 = 1/2(B_0^2 + 1/2\,\mu^2)$	dimensionless
T_2	T2	Term in definition of θ_0 $T_2 = 1/3\,B_0^3 + 1/2\,\mu^2 B_0$	dimensionless
T_3	T3	Term in definition of θ_0 $T_3 = 1/4\,B_0^2(B_0^2 + \mu^2)$	dimensionless
T_4	T4	Term in definition of θ_0 $T_4 = 1/2\,\mu(B_0^2 + 1/4\,\mu^2)$	dimensionless
V	V	Aircraft speed	ft/s
V_c	VC	Speed of sound at the given operational altitude	ft/s
V_{FIN}	VFIN	Highest aircraft speed to be considered	kn

Term	Mnemonic	Definition	Units
V_{KT}	VKNOT	Aircraft speed	kn
V_{rf}		Local velocity at the point where fuselage lift is assumed to act	ft/s
V_{rt}		Local velocity at the horizontal stabilizer	ft/s
V_T	VT	Main rotor tip speed due to rotation $V_T = \Omega R$	ft/s
$V_{t_{STA}}$	VTSTA	Vertical fin station	in.
VT_t	VTT	Tail rotor tip speed due to rotation	ft/s
W	W	Weight of main rotor blade/ft	lb/ft
w		Downwash velocity	ft/s
w_f		Downwash velocity where fuselage lift is assumed to act	ft/s
W_{FAC}	WFAC	Downwash factor from main rotor onto fuselage	dimensionless
W_{FAC_t}	WFACT	Downwash factor from main rotor onto tail	dimensionless
W_L	WL	Distance from cg to wing station	ft
WNG_{STA}	WNGSTA	Wing station	in.
W_T	WT	Tip weight	lb

Term	Mnemonic	Definition	Units
w_t		Downwash velocity at the horizontal stabilizer	ft/s
W/V_T	WVT	.Ratio of main rotor downwash to tip velocity $C_T/2\mu$	dimensionless
W/VT_t	WVTT	Ratio of downwash to tip velocity of the tail rotor	dimensionless
X_f	XF	Distance aft of cg where fuselage moment and lift are assumed to be acting	ft
X_s	XS	Radius outboard of which main rotor blade stall may be present	dimensionless
X_0	X0	Radius inboard of which main rotor blade stall may be present (due to inflow ratio and blade twist)	dimensionless
Y	Y	Distance between cg and RTR_{STA}	ft

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